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TECHNICAL REPORT

SPACE STATION MISSION SIMULATION

MATHEMATICAL MODEL

Prepared Under Contract No. NAS1-5874 by
OPERATIONS RESEARCH SECTION
Fort Worth Division of General Dynamics

for
LANGLEY RESEARCH CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Hampton, Virginia

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Hampton, Virginia

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SUMMARY

This document contains a detailed technical discussion of the results of the Development of a Space Station Mission Simulation Mathematical Model study. This work was performed by the Fort Worth Division of General Dynamics for the NASA Langley Research Center, Hampton, Virginia, under contract NAS1-5874.

In studies previous to this one a Manned Orbital Research Laboratory (MORL) system concept capable of fulfilling basic space-related research and development objectives was derived. The system complexity, operational requirements, and high resource utilization rates generated a need for a detailed mathematical model, with attendant computer program, which would provide flexible scheduling and management techniques for efficient implementation of the MORL mission concept. The results of the analyses which formed the basis of the model structure, as well as a description of the model and its applications, are presented within this report.

The model, which consists of three computer procedures, is in general suited to problems involving the effectiveness of a medium-sized earth-orbital space station. The division of the model provides the model user with a wide range of options whereby he may select the one best-suited to his needs. The first procedure

provides a means for examining space station problems on a broad, gross basis. The second procedure can be used to establish a mission plan similar to that which would be made prior to an actual mission. The third procedure enables detailed simulations of space station missions. As previously stated, the MORL system concept was used as a basis for the model's formulation, and MORL-related data constitute the majority of the library supplied with the model.

This report is the second volume of a two-volume documentation. Volume I contains a 20-page summary of the work performed under this contract. Detailed flow charts, instructions on model usage, and library data are contained in separate documentations.

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1.0 INTRODUCTION

This report contains the final technical documentation for the contract NAS1-5874, Development of a Space Station Mission Simulation Mathematical Model. The objective of this study was to develop a mathematical model and attendant computer program to simulate space station missions.

A Manned Orbital Research Laboratory (MORL) system concept, capable of fulfilling basic space-related research and development objectives, has been derived through previous studies. A need was thus generated for a detailed mathematical model which would, by effective utilization of previously developed space station data and data to be generated in the future, serve as an analytical tool and provide a management aid for the efficient implementation of a MORL or future programs.

This model provides a serviceable tool for analyzing the variables in a MORL program and determining their interacting effects upon program parameters. It will allow the analyst to perform integrated studies of various MORL programs, thus reducing the likelihood of decisions being made without full consideration of the total mission or system. The integrated analysis approach should be most fruitful in these specific study areas: (1) crew-related factors, (2) station operations, (3) system analysis, (4) resource allocations, (5) operational concepts, and (6) mission planning (see Table 1-1).

The key considerations and provisions which were factored into the model are depicted in Figure 1-1. The model is structured for easy updating and flexible operation to accommodate new data and new concepts as the space station program evolves. In addition, the particular needs of the model user have been considered. Numerous options, both program and input, have been provided to reduce peripheral output and unnecessary operations. Care has also been taken to assure that the presence of these options does not complicate model usage.

The model is suited to the solution of problems which involve mission concepts, system analyses, resource analyses, and mission planning. Comparative studies are generally performed by controlling problem input. For example, an alternative experiment program can be compared and evaluated by reading in the applicable data in lieu of the baseline experiments library. However, a complete baseline library is provided in the model. Special library is used only when required for a particular problem.

Table 1-1 ANALYTICAL APPLICATIONS

CREW-RELATED FACTORS

Selection of the optimum crew skill mixes for different experimental programs

Evaluation of variable work periods and crew rotational effects upon the experimental program

Determination of effects of operational concepts upon man-hour availability for experimental work

Evaluation of crew side and mission duration trade-offs.

SYSTEMS ANALYSES

Provision of trade-off data for use in studying the effects of system interactions

Assessment of the effects of modifying or changing systems characteristics upon the mission evaluation parameters.

OPERATIONAL CONCEPTS

Evaluation of proposed changes in the mission plan and/or operational concepts such as the length of the supply interval and the allowable work loads for the crew members, respectively.

RESOURCE ALLOCATIONS AND MISSION PLANNING

Provide insight into mission requirements, resulting in efficient allocation of critical resources such as man-hours, electrical power, etc.

Location of bottlenecks and potential trouble spots in proposed programs, such as insufficient logistics support capability.

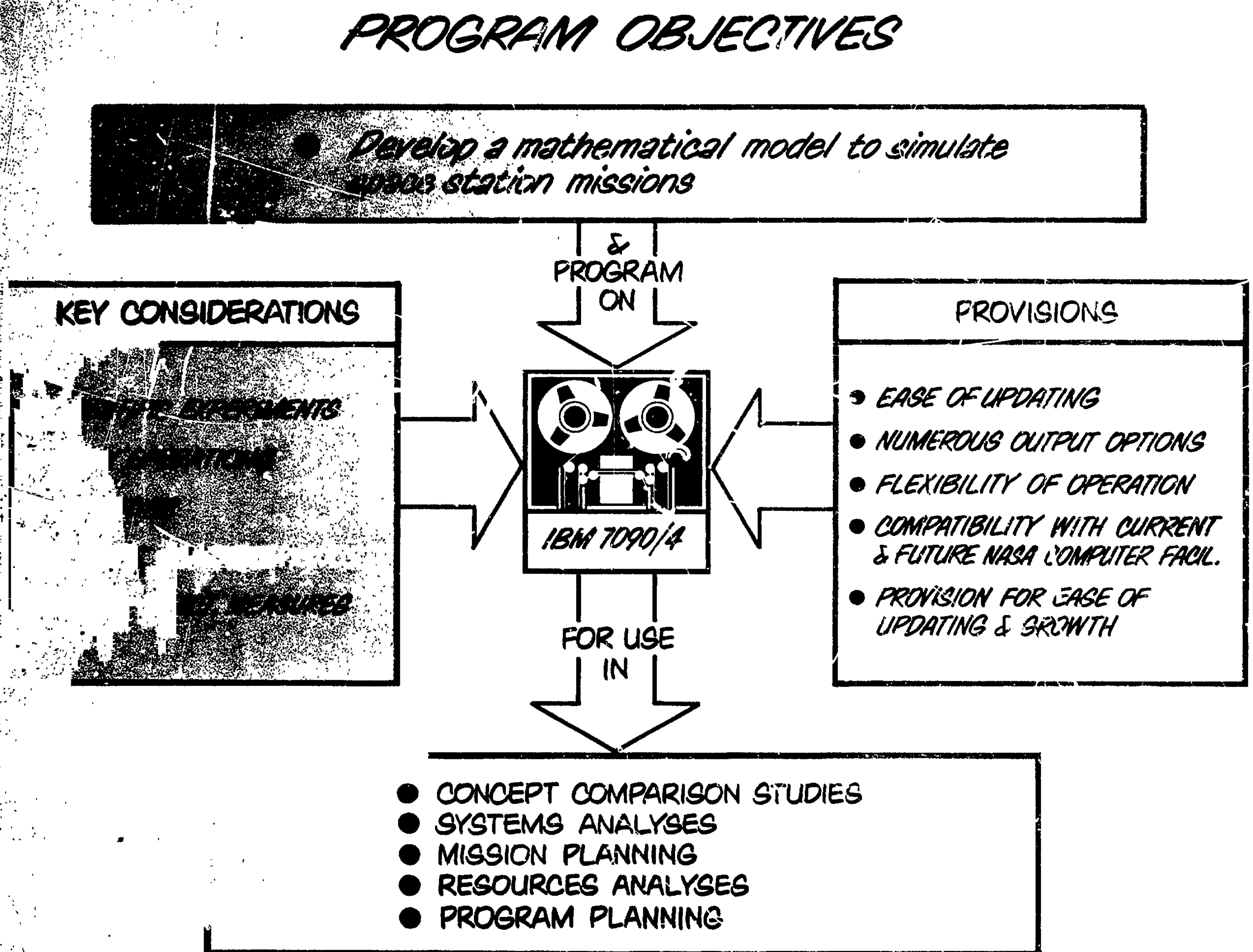

PROGRAM OBJECTIVES
Develop a mathematical model to simulate space station missions
& PROGRAM ON
KEY CONSIDERATIONS
IBM 7090/4
PROVISIONS
EASE OF UPDATING
NUMEROUS OUTPUT OPTIONS
FLEXIBILITY OF OPERATION
COMPATIBILITY WITH CURRENT & FUTURE NASA COMPUTER FACIL.
PROVISION FOR EASE OF UPDATING & GROWTH
FOR USE IN
CONCEPT COMPARISON STUDIES
SYSTEMS ANALYSES
MISSION PLANNING
RESOURCES ANALYSES
PROGRAM PLANNING

Figure 1-1

2.0 DEVELOPMENT APPROACH AND STUDY PLAN

The study plan which was followed in the development of the Space Station Mission Simulation Mathematical Model consisted of two basic phases (illustrated in Figure 2-1). Analyses in the first phase were directed toward (1) identifying and defining the requirements for constructing the model, (2) determining the parameters and functional relationships to be incorporated into the model, and (3) development of a detailed model structure concept. Emphasis was placed on developing a concept which would permit the efficient use of the model in a wide variety of specific studies while eliminating large quantities of irrelevant output. In the second phase of the study, the detailed logic of the various routines formulated during Phase I was developed and programmed. The second phase culminated in the validation and checkout of the model and implementation at Langley Research Center.

APPROACH TO MODEL DEVELOPMENT

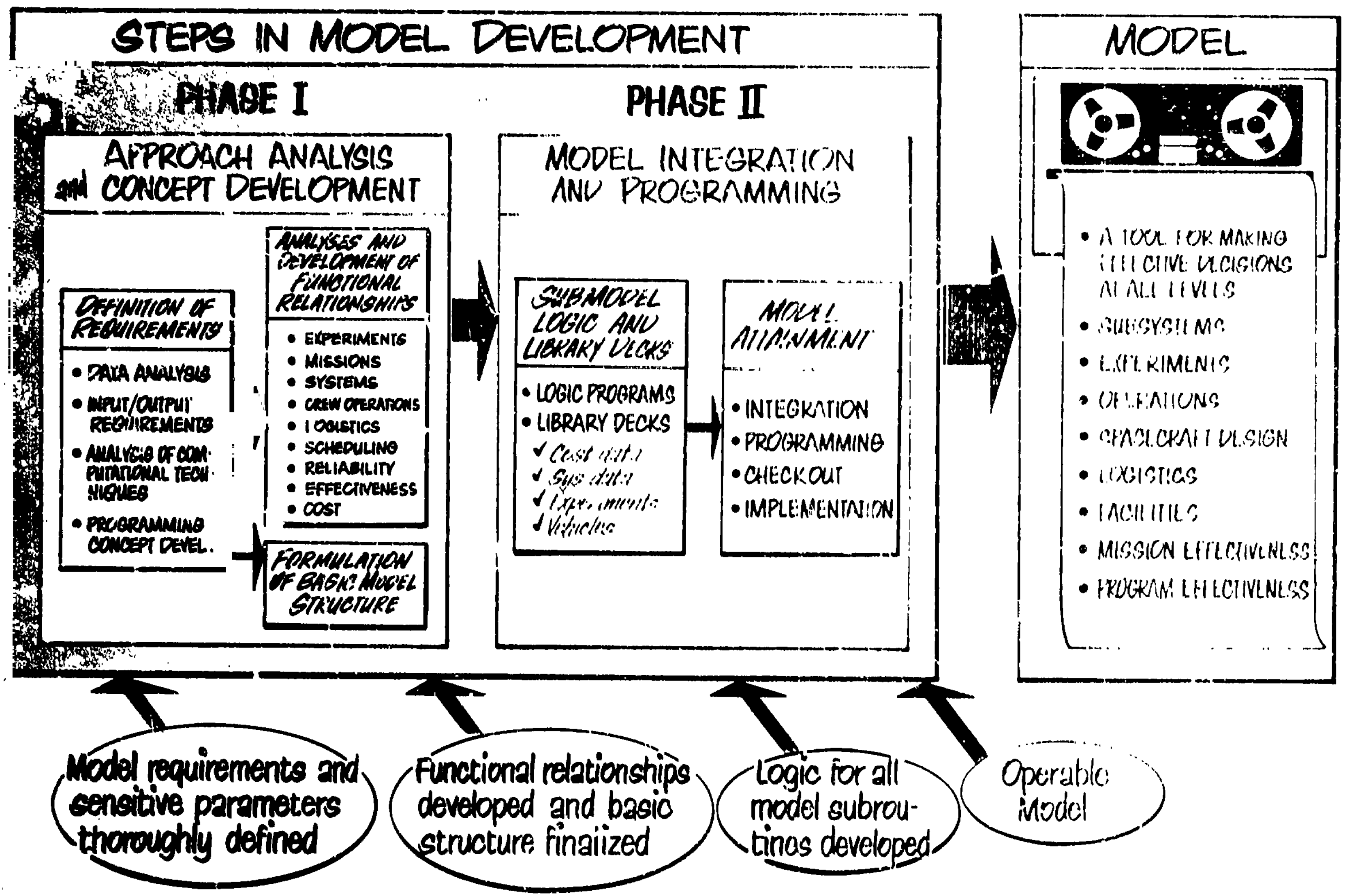
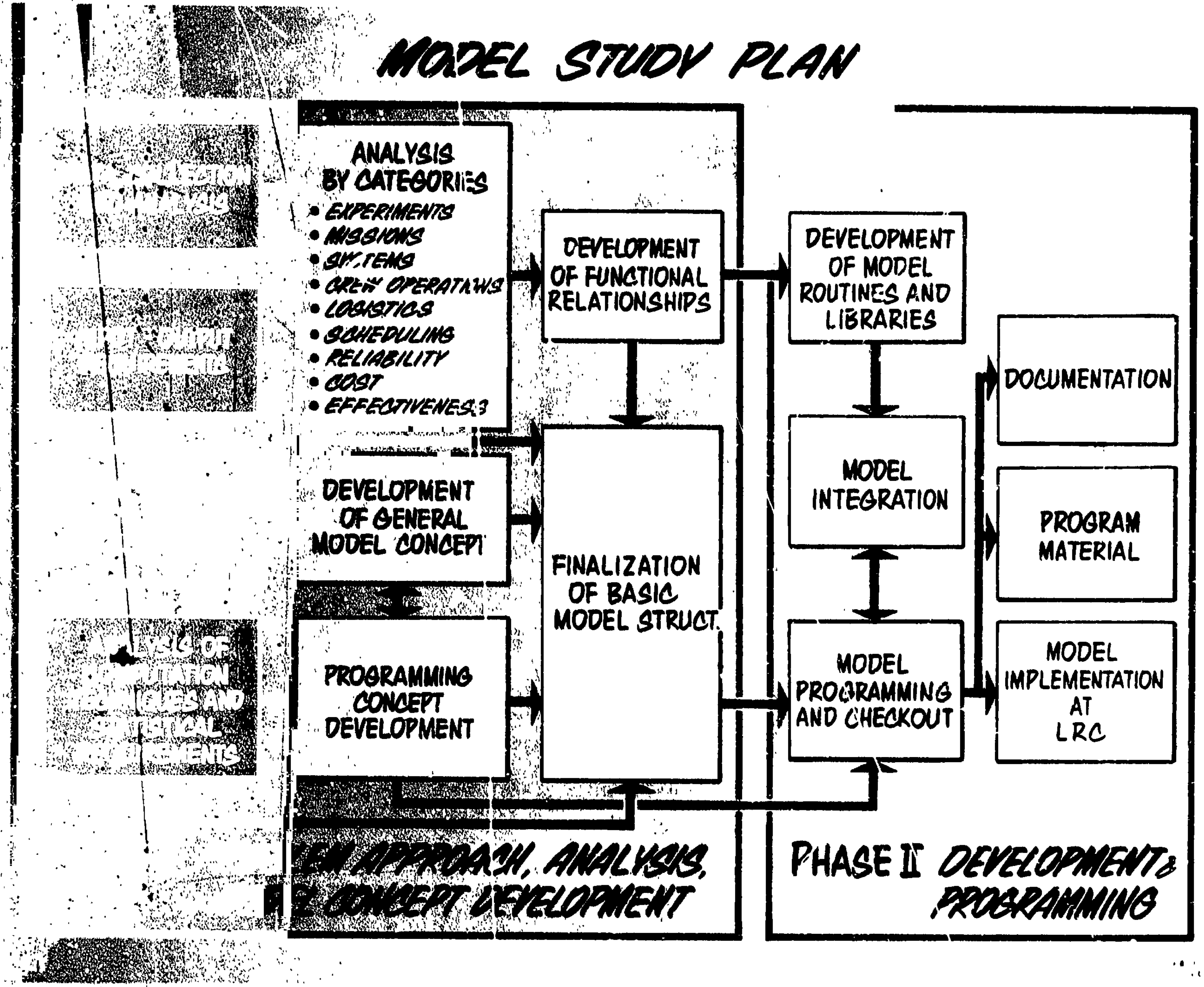


Figure 2-1

The relationships among the major task areas are illustrated in the study plan shown in Figure 2-2. The objectives in the data collection and analyses phase were (1) to analyze the available MORL data and (2) to perform the analyses necessary to meet model development requirements. In establishing the input and output requirements, the objectives were to determine the mission parameters; to derive vehicle, experiments, and systems descriptions for input into the model; and to establish a listing of model outputs. The purpose of the model application and utilization requirements task was to define the objectives of model usage; these objectives included system trade-offs, operational analyses, cost-effectiveness studies, reliability evaluations, logistics analyses, crew-related analyses, experiments analyses, etc.

The computational techniques and statistical requirements analysis dealt with simulation techniques, error analyses, and statistical inferences. Input-output relationships, resource requirements, and parameter relationships were included in the detailed analyses. Areas of concern in developing the general model concept were the establishment of basic subroutines, analyses of promising structures, and establishment of simulation techniques. The programming-concept development included analyses of programming methods, verification of concepts, and consideration of specific



MODEL STUDY PLAN
ANALYSIS BY CATEGORIES
• EXPERIMENTS
• MISSIONS
• SYSTEMS
• CREW OPERATIONS
• LOGISTICS
• SCHEDULING
• RELIABILITY
• COST
• EFFECTIVENESS
DEVELOPMENT OF GENERAL MODEL CONCEPT
PROGRAMMING CONCEPT DEVELOPMENT
DEVELOPMENT OF FUNCTIONAL RELATIONSHIPS
FINALIZATION OF BASIC MODEL STRUCT.
APPROACH, ANALYSIS, CONCEPT DEVELOPMENT
DEVELOPMENT OF MODEL ROUTINES AND LIBRARIES
MODEL INTEGRATION
MODEL PROGRAMMING AND CHECKOUT
DOCUMENTATION
PROGRAM MATERIAL
MODEL IMPLEMENTATION AT LRC
PHASE II DEVELOPMENT & PROGRAMMING

Figure 2-2

programming related to this study. In addition, functional relationships were developed, as needed, in each section of the model. The results of all of these tasks are included in the basic model structure.

During Phase II, completed tasks included the development of logic diagrams and library data, as well as integration, programming and checkout of the model. At the completion of Phase II, the model was then demonstrated and implemented at Langley Research Center.

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3.0 MODEL CONCEPT

3.1 Introduction

The Space Station Mission Simulation Mathematical Model consists of three computer programs, each applicable to a different phase of the operation. The basic model concept is illustrated in Figure 3-1. Preliminary analyses are performed with the Preliminary Requirements Model (PRM); mission plans are developed by the Space Station Model in the Planning Mode; and mission simulation is accomplished by the Space Station Model in the Simulation Mode. The Preliminary Requirements Model generates output data and prepares libraries for use by the Planning Mode; the Planning Mode provides a data tape for use in the Simulation Mode and also produces its own printed output. The Simulation Mode, in addition to receiving output from the Planning Mode, prepares a data tape for input to other Simulation Mode runs.

By dividing the model into three programs, run time and user time are conserved, since the model user may select various levels of refinement through choices of models or model modes to be used. For example, in the early stages of mission plan evaluation, the Preliminary Requirements Model can be used to make a gross evaluation of the mission parameters and to delineate the relations between these parameters. The requirements for many studies in which no

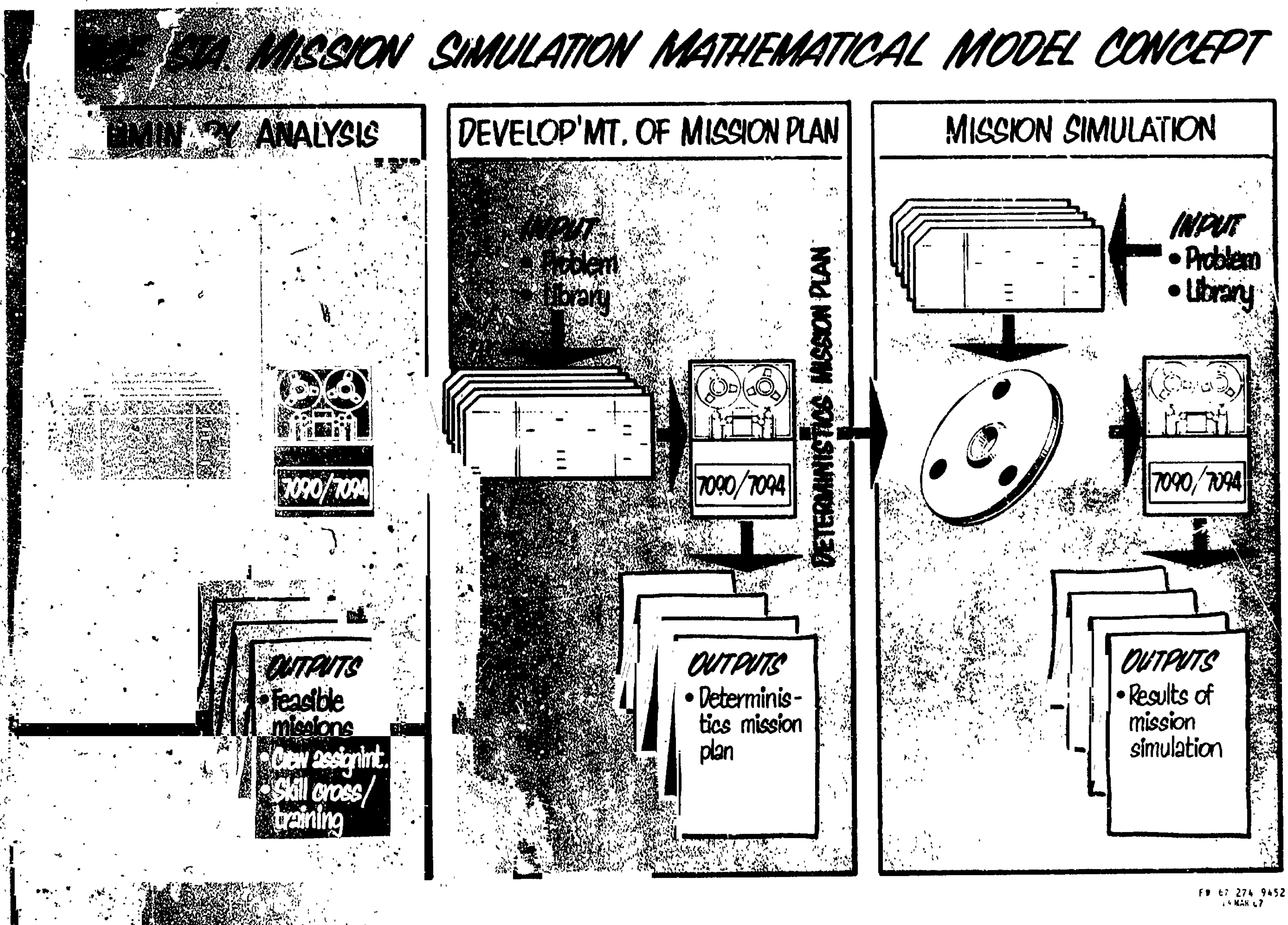

MISSION SIMULATION MATHEMATICAL MODEL CONCEPT
ANALYSIS
7090/7094
OUTPUTS
• Feasible missions
• Crew assignmt.
• Skill cross/ training
DEVELOP'MT. OF MISSION PLAN
INPUT
• Problem
• Library
7090/7094
OUTPUTS
• Deterministics mission plan
DETERMINISTICS MISSION PLAN
MISSION SIMULATION
INPUT
• Problem
• Library
7090/7094
OUTPUTS
• Results of mission simulation

Figure 3-1

detail is needed can be satisfied within this one phase. Such data can be used in assessing the feasibility of various mission concepts and in making an initial determination of mission requirements.

The Planning Mode can be used to obtain a refined estimate of the mission parameters and to provide detailed data for assessing the effectiveness of the various station activities. The data provided in this phase will satisfy many additional studies, thus the model user may select a more refined level of detail to suit his problem needs. Computer run time and operation are additionally facilitated in these first two phases by the fact that the PRM and Planning Modes are highly efficient deterministic models.

Finally, the Simulation Mode provides a means for determining the effects of contingencies on the mission plan, and a highly sophisticated evaluation of the mission parameters can be made. The extent of deviation by the simulated mission from the mission plan may be assessed. Data obtained from this mode of operation can be used to determine contingency procedures and requirements and to estimate the degree of confidence which can be achieved in realizing mission goals.

The program utilization sequence (Figure 3-2) illustrates the process of improvement in the quality of model output. A problem progresses from the gross assessment stage performed by

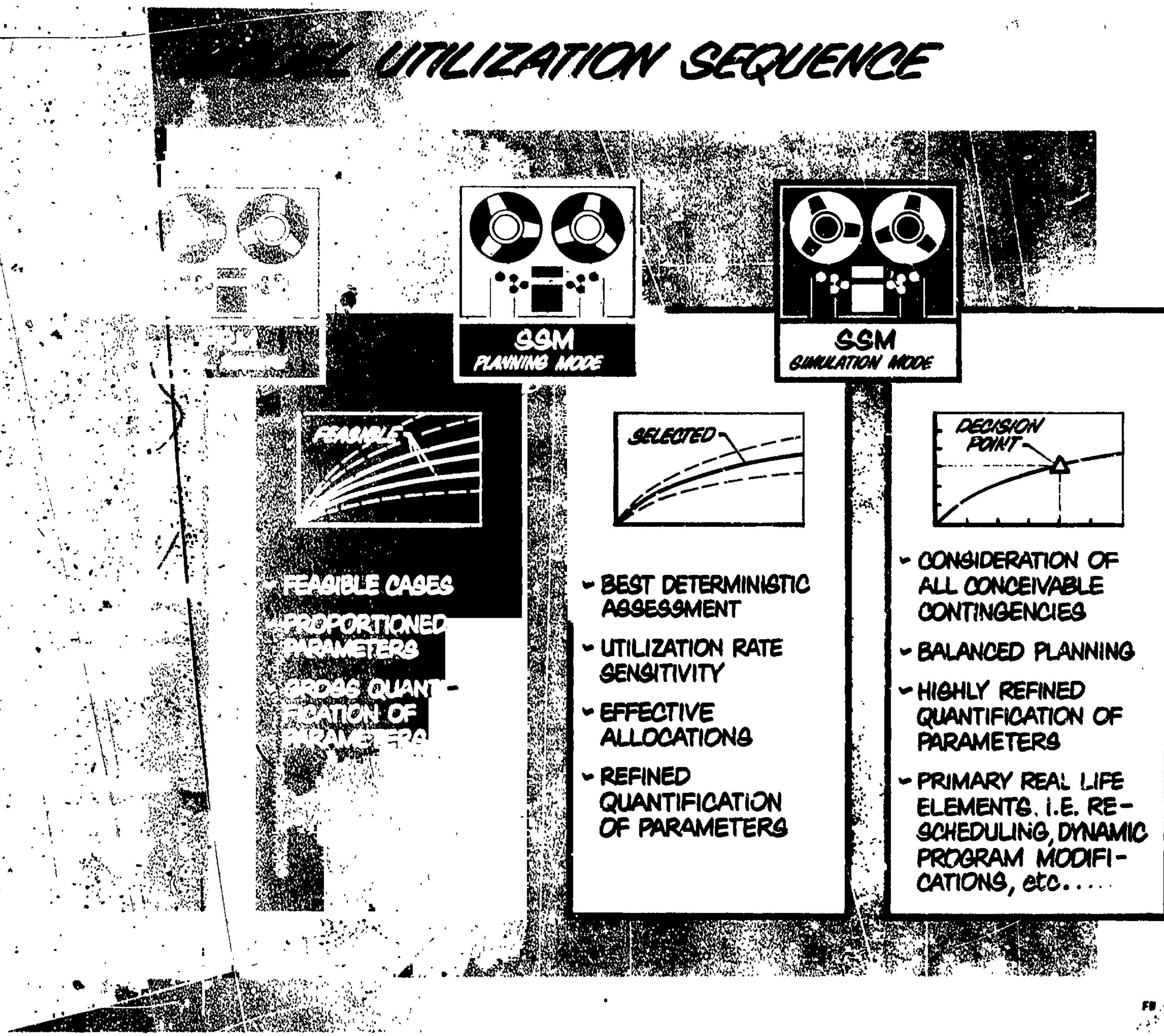

UTILIZATION SEQUENCE
SSM
PLANNING MODE
SSM
SIMULATION MODE
FEASIBLE
FEASIBLE CASES
PROPORTIONED PARAMETERS
SELECTED
BEST DETERMINISTIC ASSESSMENT
UTILIZATION RATE SENSITIVITY
EFFECTIVE ALLOCATIONS
REFINED QUANTIFICATION OF PARAMETERS
DECISION POINT
CONSIDERATION OF ALL CONCEIVABLE CONTINGENCIES
BALANCED PLANNING
HIGHLY REFINED QUANTIFICATION OF PARAMETERS
PRIMARY REAL LIFE ELEMENTS. I.E. RE-SCHEDULING, DYNAMIC PROGRAM MODIFI-CATIONS, etc....

Figure 2-2

the PRM, to the detailed deterministic assessment of the Planning Mode, and finally to the specific case points of the Simulation Mode.

3.2 Preliminary Analysis

The operational sequence of the Preliminary Requirements Model is depicted in Figure 3-3. In general, the PRM operates on a logistics cycle which conforms (subject to some modifications due to launch constraints) to a crew rotation cycle plan. The logistics routine is used to determine the width of the launch interval and the payload capacity available for experimental equipment. Based upon the skill mixes possessed by candidate crewmen, a crew is selected and assignments are scheduled for each crewman. The program continues to the next launch interval, or until the mission is completed. At the end of the mission, a summary is made of the above parameters as well as other effectiveness measures.

The key features of the PRM (described fully in Section 5.0) are its ability to select crewmen based on skill cross-training considerations and to make initial crew assignments. This information is subsequently used by the Planning Mode.

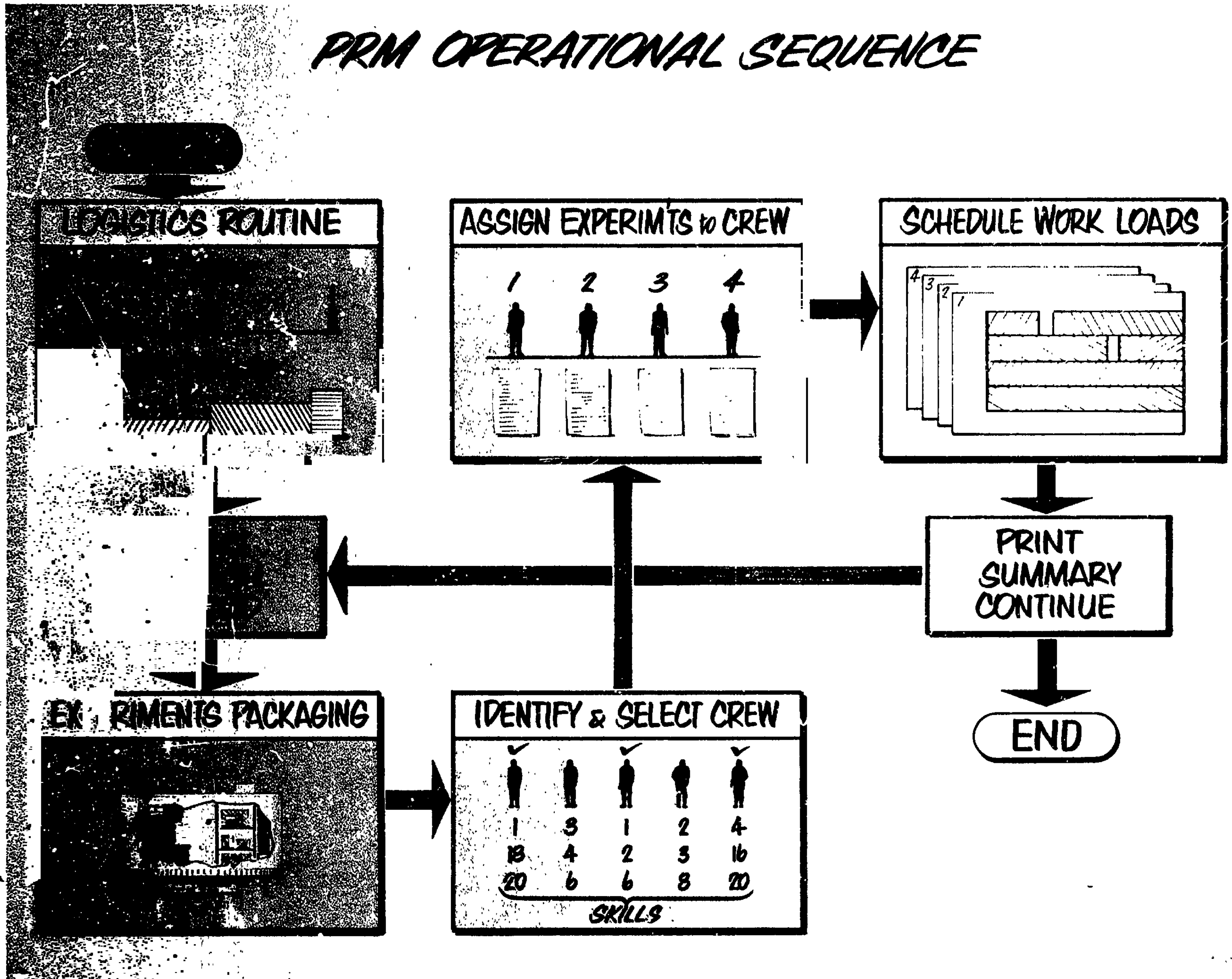

PRM OPERATIONAL SEQUENCE
LOGISTICS ROUTINE
ASSIGN EXPERIMTS to CREW
1
2
3
4
SCHEDULE WORK LOADS
4
3
2
1
PRINT SUMMARY CONTINUE
END
IDENTIFY & SELECT CREW
1 18 20
3 4 6
1 2 6
2 3 8
4 16 20
SKILLS

Figure 3-3

3.3 Development of Mission Plan

The Planning Mode of the Space Station Simulation Model develops a mission plan analogous to one which would be made prior to performing an actual mission. As previously mentioned, the Planning Mode is deterministic, using expected values for system parameters. In the Planning Mode, as in the PRM, the entire mission is viewed as a single problem, i.e., the total mission is examined in each run. Although its operational sequence is relatively simple, as shown in Figure 3-4, the Planning Mode offers considerable sophistication over the PRM. Initially, the station expendable requirements are determined for ten categories. This is accomplished by use of the station operation routine. Next, the logistics schedule is established by the use of the logistics routine. The scheduling routine is then employed to schedule the station keeping tasks and personal requirements. Experiments are next scheduled until the remaining resources or available experiments are exhausted. The evaluation routine provides a summary of the mission requirements, costs, and effectiveness. The evaluation routine includes a capability to indicate confidence versus number of launch vehicles or program cost required. Such an estimate is based upon the reliability of the logistics launches and provides an indication of the results that might be obtained by repetitive simulation.

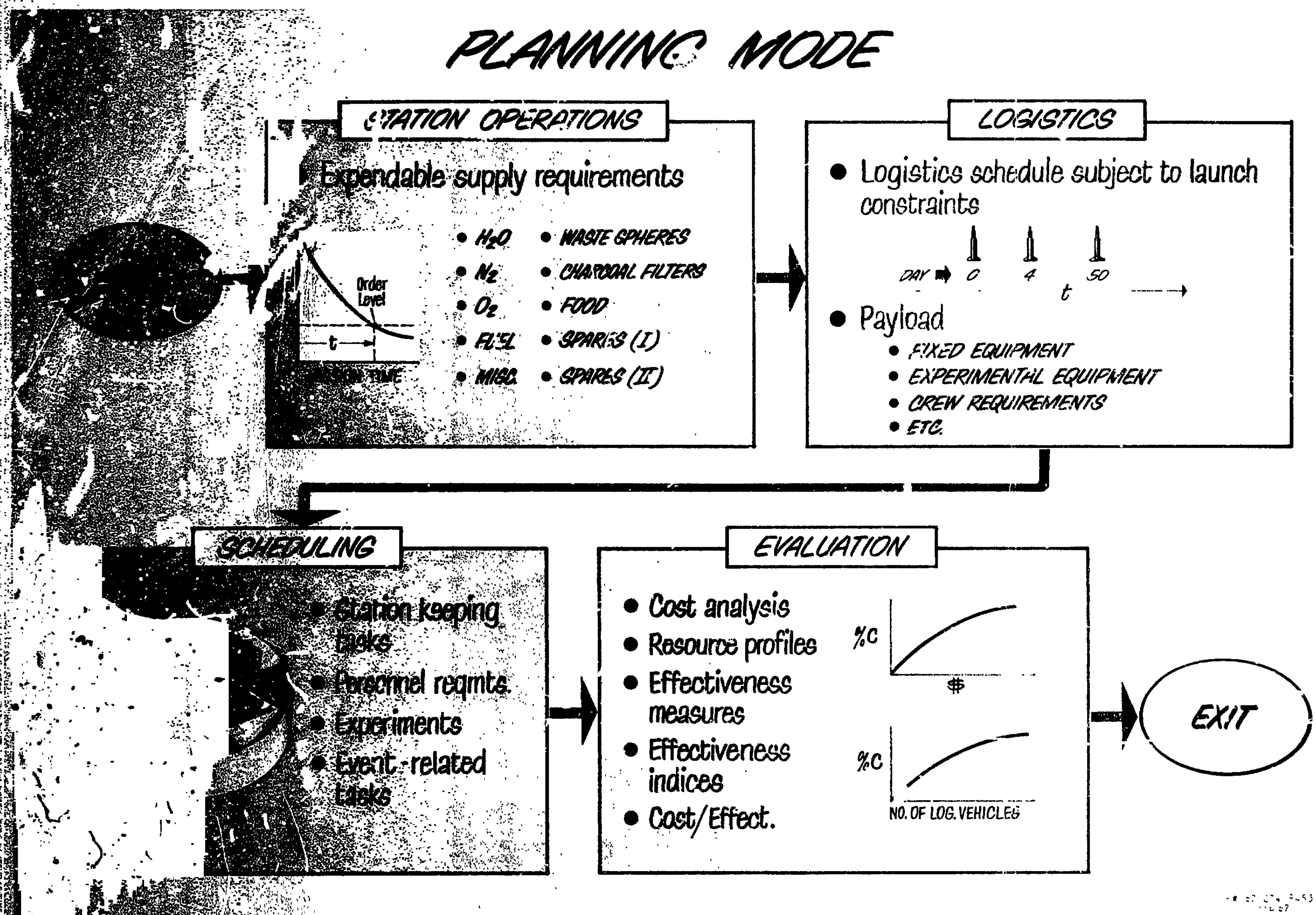

PLANNING MODE
STATION OPERATIONS
Expendable supply requirements
Order Level
t
• H_2O
• N_2
• O_2
• FUEL
• MISC.
• WASTE SPHERES
• CHARCOAL FILTERS
• FOOD
• SPARES (I)
• SPARES (II)
LOGISTICS
• Logistics schedule subject to launch constraints
DAY 0 4 50
t
• Payload
• FIXED EQUIPMENT
• EXPERIMENTAL EQUIPMENT
• CREW REQUIREMENTS
• ETC.
SCHEDULING
• Station keeping tasks
• Personnel reqmts.
• Experiments
• Event-related tasks
EVALUATION
• Cost analysis
• Resource profiles
• Effectiveness measures
• Effectiveness indices
• Cost/Effect.
%C
$
%C
NO. OF LOG. VEHICLES
EXIT

Figure 3-4

3.4 Mission Simulation

3.4.1 Introduction

Mission simulation is accomplished by the Simulation Mode of the Space Station model. The Simulation Mode provides the means for determining the effects of contingencies on the mission plan, resulting in a highly refined evaluation of the mission parameters. In this mode, the mission plan is adjusted dynamically as the mission progresses in time. The basic simulation unit, or run interval, is the time between crew arrivals. Most of the conceivable probabilistic events such as system failures, event terminations, illnesses, random phenomena occurrences, etc., are included in the library.

The event controller, shown in Figure 3-5, is the central coordinator for this mode. Since event-to-event simulation is applied, the event controller advances to each event, processes it, and proceeds to the next event in time. The routing is sometimes rather extensive, and, hence, the major subroutines are supplied with their own control programs. A description of the operation of the Simulation Mode follows.

3.4.2 Event Controller

The event controller, which serves as the central coordinating source for the Simulation Mode, has three primary functions. The first is to initiate procedures keyed to the beginning of a mission

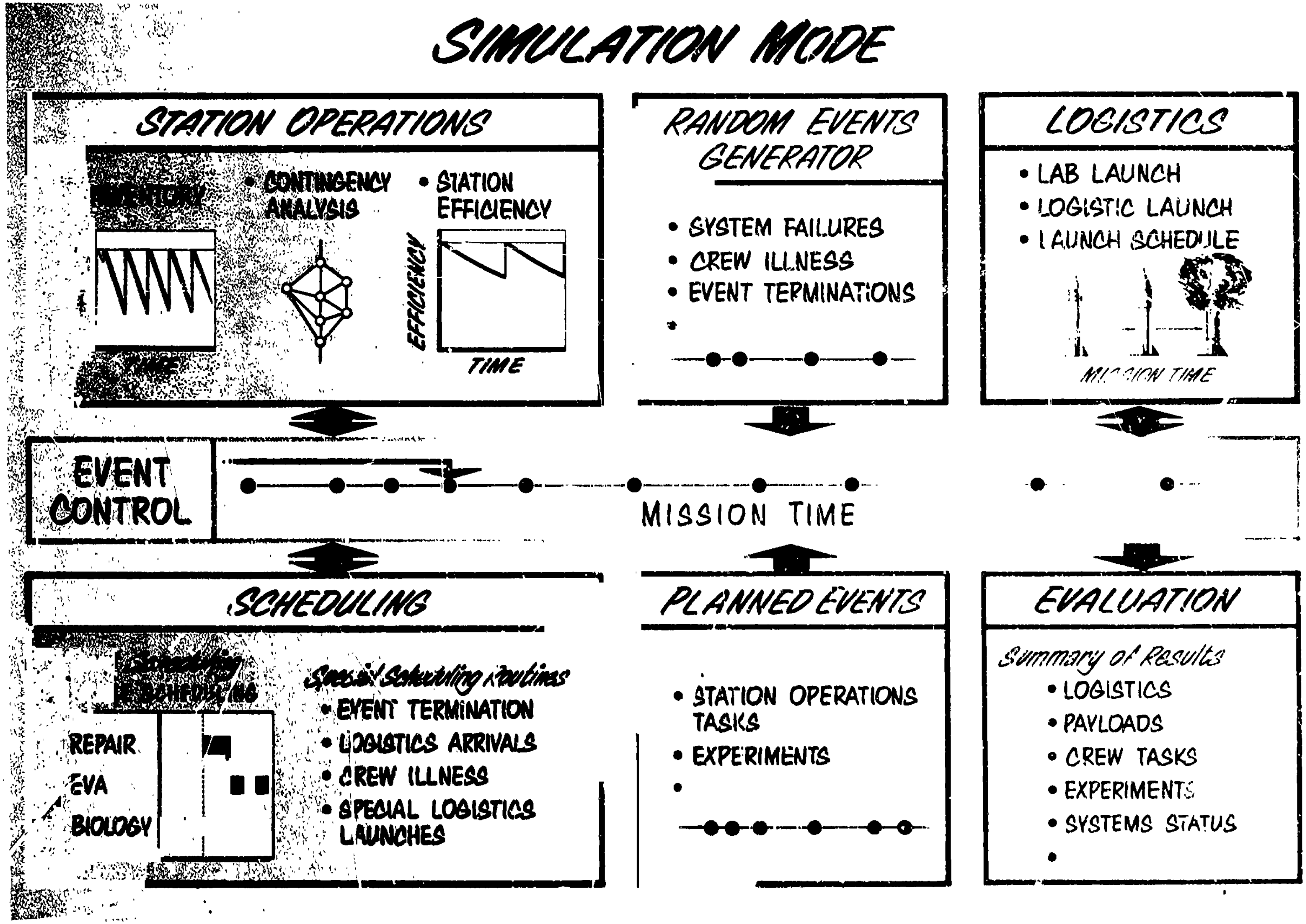

SIMULATION MODE
STATION OPERATIONS
• CONTINGENCY ANALYSIS
• STATION EFFICIENCY
EFFICIENCY
TIME
RANDOM EVENTS GENERATOR
• SYSTEM FAILURES
• CREW ILLNESS
• EVENT TERMINATIONS
•
LOGISTICS
• LAB LAUNCH
• LOGISTIC LAUNCH
• LAUNCH SCHEDULE
EVENT CONTROL
MISSION TIME
SCHEDULING
REPAIR
EVA
BIOLOGY
• EVENT TERMINATION
• LOGISTICS ARRIVALS
• CREW ILLNESS
• SPECIAL LOGISTICS LAUNCHES
PLANNED EVENTS
• STATION OPERATIONS TASKS
• EXPERIMENTS
•
EVALUATION
Summary of Results
• LOGISTICS
• PAYLOADS
• CREW TASKS
• EXPERIMENTS
• SYSTEMS STATUS
•

Figure 3-5

simulation, such as loading input and library data from the planning mode, launching the laboratory, and obtaining initial random event times. The second is to perform the functions necessary to begin the simulation of a logistics launch interval (other than the checkout period), such as reestablishing the status of the station and generating the initial schedule for the period. The third function is to provide a mechanism for proceeding from event to event, processing them in the order of their (random) times of occurrence.

3.4.3 Beginning of Simulation

At the start of a mission simulation, a problem data deck is loaded and pertinent libraries are loaded from a tape generated in the Planning Mode. Initialization procedures are then executed for the station operations routine and the logistics routine. Control is next transferred to logistics routine for simulation of the laboratory launch. As many as three attempts will be made to obtain a successful launch. If three failures occur, the problem is terminated. If a successful launch is obtained, control is returned to event controller, and simulation of the unmanned checkout period follows. The event controller advances the "calendar" (simulated time) to the end of the unmanned checkout period to effect the following events:

1. Scheduling of logistics launch number one

2. Updating of inventory and computing of order amounts

3. Packaging the payload for the first launch

4. Simulating the first logistics launch.

The updating of the inventory is accomplished by use of the stations operations routine, the other events are functions of the logistics routine. It is assumed that men arrive on the first logistics launch, thus ending the unmanned checkout period. Event controller then coordinates the scheduling, packaging, and launching of the second and succeeding logistics launches until a full crew (at least six men) is on board. The calendar time is advanced at each step. At this point (the end of the manned checkout) the random events which have been included are the simulation of success or failure of the laboratory and logistics launches. A variable introduced in the problem data and applied at this time is the probability of successful checkout, which includes possible system failures. This probability is used in simulation of the success or failure of the entire checkout period. If a failure occurs, the problem is terminated. If the checkout period is successful, the mission proceeds to the operational period. Since none of the experimental program is carried out during the checkout period, the primary concern is the success or failure of the checkout as an entity, rather than simulation of individual events within the period. That is, no attempt is made to schedule and process individually those events which occur during the checkout period. The advantage to be gained by event-to-event checkout does not appear to warrant this slight increase in accuracy. It should be noted that computation of expendables consumed, packaging of logistics payloads, and simulation of logistics launches are performed for this period.

After a successful checkout and an initial event schedule is established, the random events generator initializes the time of occurrence of each random event in the event table (see Table 3-1), and processing of the random events begins. These events are described fully in other sections of the report.

3.4.4 Beginning of a Launch Interval (After the Checkout Period)

At the beginning of any interval of time after checkout is completed, the tape generated at the end of the previous interval is read into the event controller. The flight mechanics subroutine and a reestablished events table are used in scheduling the next launch. The scheduling routine simulates loading of the resources available, scheduling of the docking and loading tasks, loading of the in-progress tasks and experiments, and establishment of the initial schedule for the period. Processing of the random events then begins. At the end of each interval a tape of the status of the mission parameters is generated for use in the next interval.

Table 3-1 EVENT TABLE

Event Number	Event
1	Abort
2	Evaluate Abort
3	Contagious disease
4	Major Illness
5	Minor Illness
6 - 7	Open
8	Schedule for Major Illness
9	F - Requirement - Logistics
10	Arrival of Special Launch
11	Schedule for Repair Task
12	Open
13 Thru 712	Parts Failure
713	Open
714	Reschedule Due to Change in Resource Level (Repair Task)
715	Check Station Efficiency
716	Critical Time
717	Open
718 Thru 757	Schedule Experiment Termination - Event Termination
758	Open
759	Schedule Launch to End Interval
760	Expendable Update
761	Order Payload
762	Package Payload
763	Launch Vehicle
764	Schedule Vehicle Arrival (The One That Ends the Interval)
765	Evaluate Interval
766 Thru 770	Open

3.4.5 Processing Random Events

Processing of the random events by the event controller is accomplished by selecting the earliest of the times of occurrence, updating the calendar to this time, and transferring control to the appropriate section of the model (e.g., logistics, scheduling, etc.). When control is returned to the event controller, the event being processed has been given a time for its next occurrence, and, again, the earliest occurrence time among all events is picked. This cycle continues until the arrival of a crew-carrying vehicle (signaling the end of the interval) at which time an evaluation is performed.

3.5 Model Operation

The Preliminary Requirements Model (PRM) affords the model user with numerous program options, as shown in Figure 3-6. A logistics routine may be used in the PRM if desired, or the launch intervals may be defined by the model user. Use of a skill optimization routine is also an option, or a matrix of skill crew proficiencies may be used. If the PRM run precedes a Planning Mode run, then an option is selected whereby the PRM will prepare libraries for the Planning Mode.

Data used by the Planning Mode are obtained from three sources: (1) problem data, (2) PRM prepared libraries, and (3) libraries

OPERATING THE PRELIMINARY REQUIREMENTS MODEL (PRM)

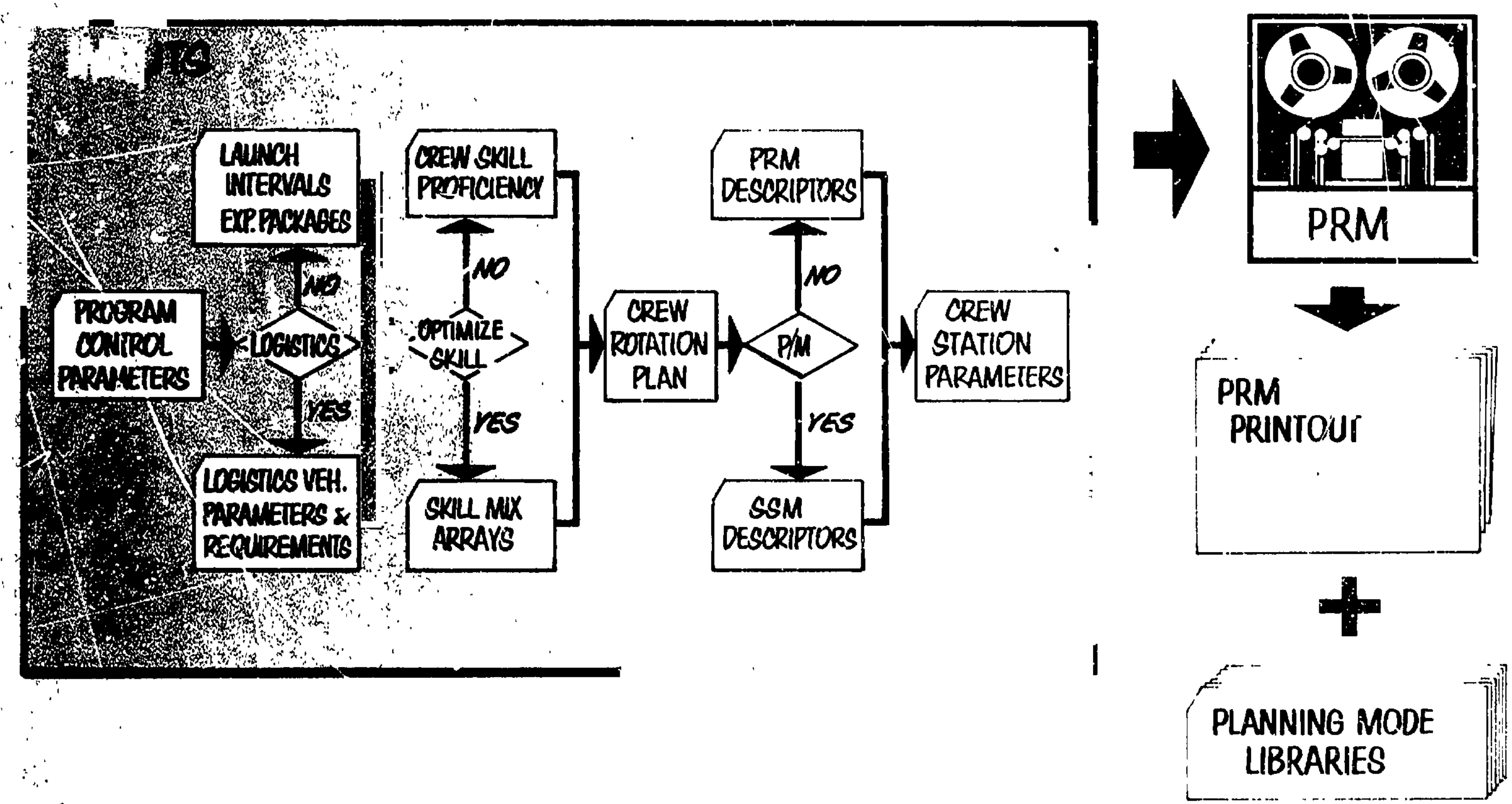


Figure 3-6

within the Planning Mode. The problem data define mission calendar start date, duration of mission, libraries to be used, orbital parameters, and experiment priorities. The experiment priority option allows the model user to express a preference in the order in which experiments are considered for scheduling.

The PRM libraries include crew task assignments, experiment assignments, crew description (such as number of crewmen, skill type, rotation, etc.), and a logistics library, as illustrated in Figure 3-7.

The Planning Mode libraries provide descriptors values for the laboratory, subsystems, station operation, tasks, and experiments. Since these data source libraries are not subject to frequent change, they may be called in block form. However, if desired, most of the entries may be altered by changing a few cards.

It is necessary that the Planning Mode be run prior to the Simulation Mode. The Planning Mode prepares a tape of the mission plan including a description of the mission, system, experiments, crew, expendable levels, etc. (Figure 3-8). Whereas the Planning Mode treats the entire mission as a problem, the Simulation Mode examines each separate interval defined by crew arrivals as a problem. These intervals may be connected, if so desired. This is accomplished by storing on tape the necessary data from the previous Simulation Mode run and using it as input in the next run.

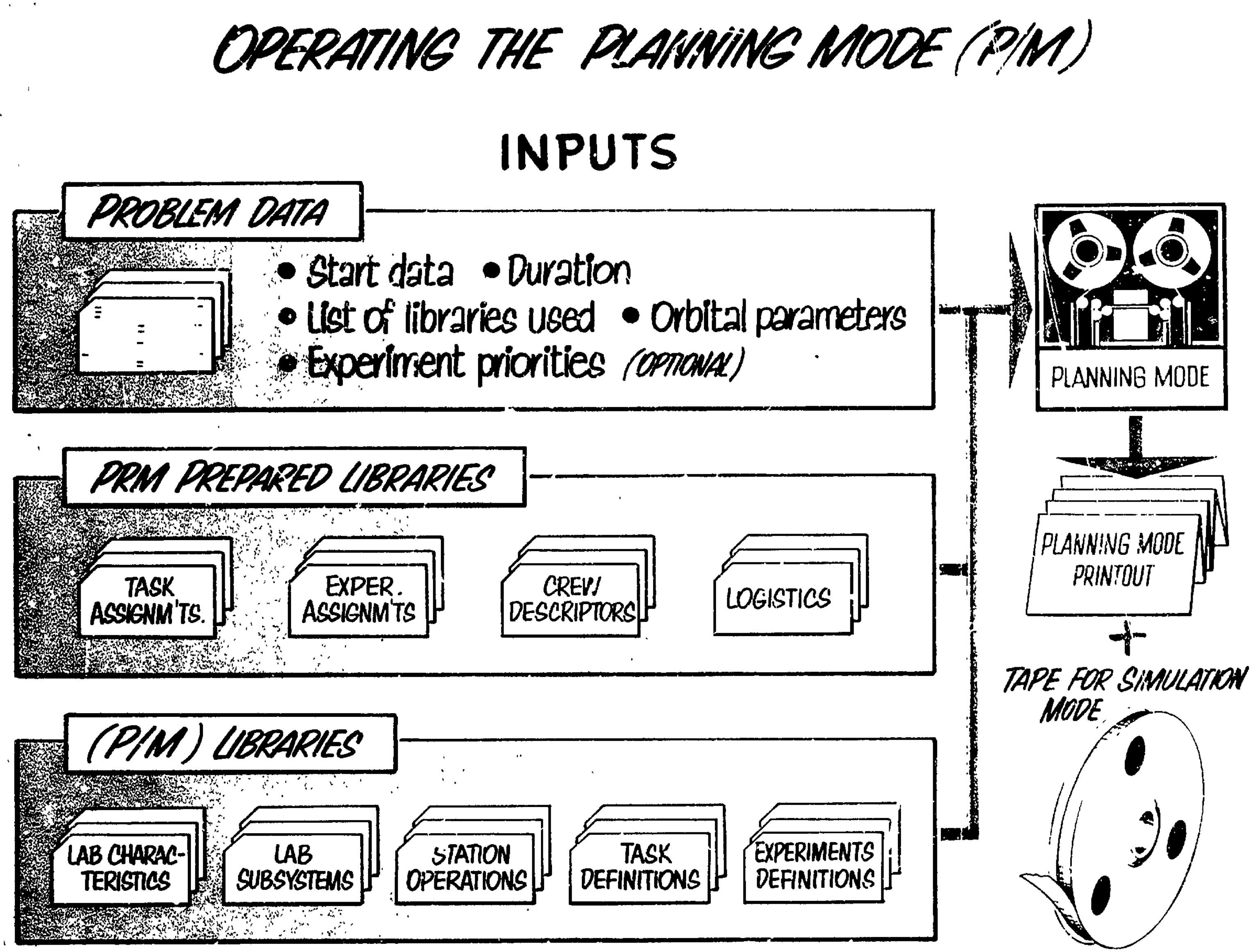

OPERATING THE PLANNING MODE (P/M)
INPUTS
PROBLEM DATA
• Start data • Duration
• List of libraries used • Orbital parameters
• Experiment priorities (OPTIONAL)
PRM PREPARED LIBRARIES
TASK ASSIGNM'TS.
EXPER. ASSIGNM'TS
CREW DESCRIPTORS
LOGISTICS
(P/M) LIBRARIES
LAB CHARAC-TERISTICS
LAB SUBSYSTEMS
STATION OPERATIONS
TASK DEFINITIONS
EXPERIMENTS DEFINITIONS
PLANNING MODE
PLANNING MODE PRINTOUT
+
TAPE FOR SIMULATION MODE

Figure 3-7

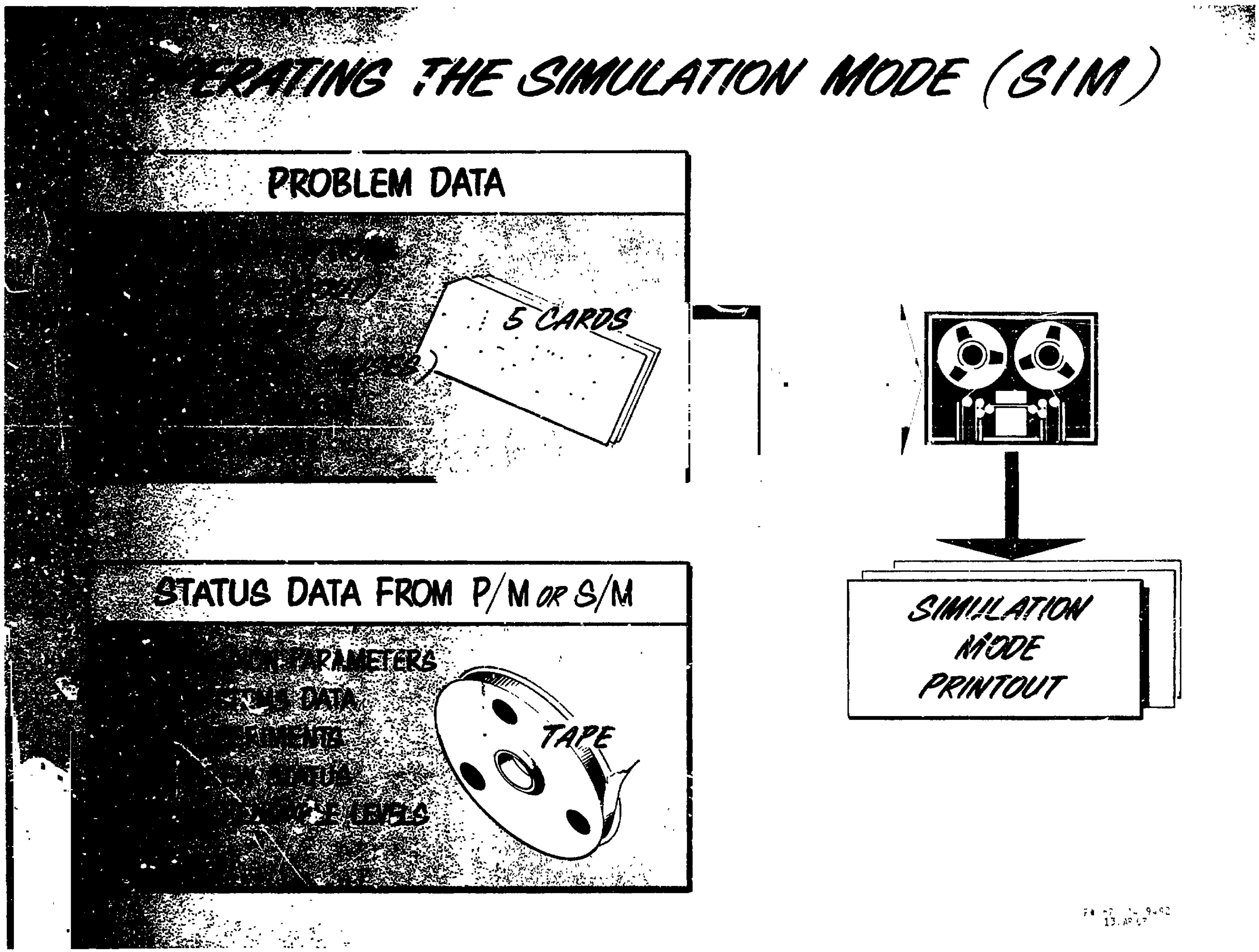

...ERATING THE SIMULATION MODE (SIM)
PROBLEM DATA
5 CARDS
STATUS DATA FROM P/M OR S/M
TAPE
SIMULATION
MODE
PRINTOUT

Figure 3-8

By generating most of the information in other modes or in library storage, the problem deck for the Simulation Mode consists of only five cards. These cards describe (1) the output options, (2) the probability of success of unmanned checkout, (3) the probability of success of abort if it becomes necessary to abandon the station, (4) the probability of failure from miscellaneous causes, and (5) the delta efficiency level required for ordering special logistics launches. In summary, the three phases of the operation are as follows:

1. Preliminary Analysis - Performed in the PRM to determine gross mis ion parameters, crew assignments, and skill mixes.
2. Development of Mission Plan - Performed in the Planning Mode to provide (1) a deterministic mission assessment extensively using available data, (2) sensitivity to resource utilization rates, (3) effective allocations of resources, and (4) considerable refinement of effectiveness measures and mission parameters.
3. Mission Simulation - Performed in the Simulation Mode to provide (1) consideration of most conceivable contingencies, (2) primary real life elements such as rescheduling, dynamic program modifications, etc., (3) highly refined quantification of parameters, and (4) improved mission planning.

4.0 MODEL APPLICATIONS AND UTILIZATION

4.1 Introduction

Prior to the construction of the S ace Station Mission Simulation Model, extensive analyses were performed to ascertain that the model would be responsive to program needs. Model applications and utilization requirements were analyzed and the results of these analyses formed the bases upon which the model concept and basic structure were formulated.

4.2 Scope of Model Utilization

The Space Station Mission Simulation Mathematical Model has been designed to treat the major operational aspects of a space station system in the preliminary design and R&D phases, as shown in Figure 4-1. It can be used to evaluate the responsiveness of a space station design to various mixes of missions, experiments, crew skills, and logistics systems and is capable of employing effectiveness measures such as mission duration, logistics requirements, experiment scheduling efficiency, etc.

Ultimately, the model may be expanded in accuracy and detail and employed for detail mission planning and for some control functions during space station operational phase. In this

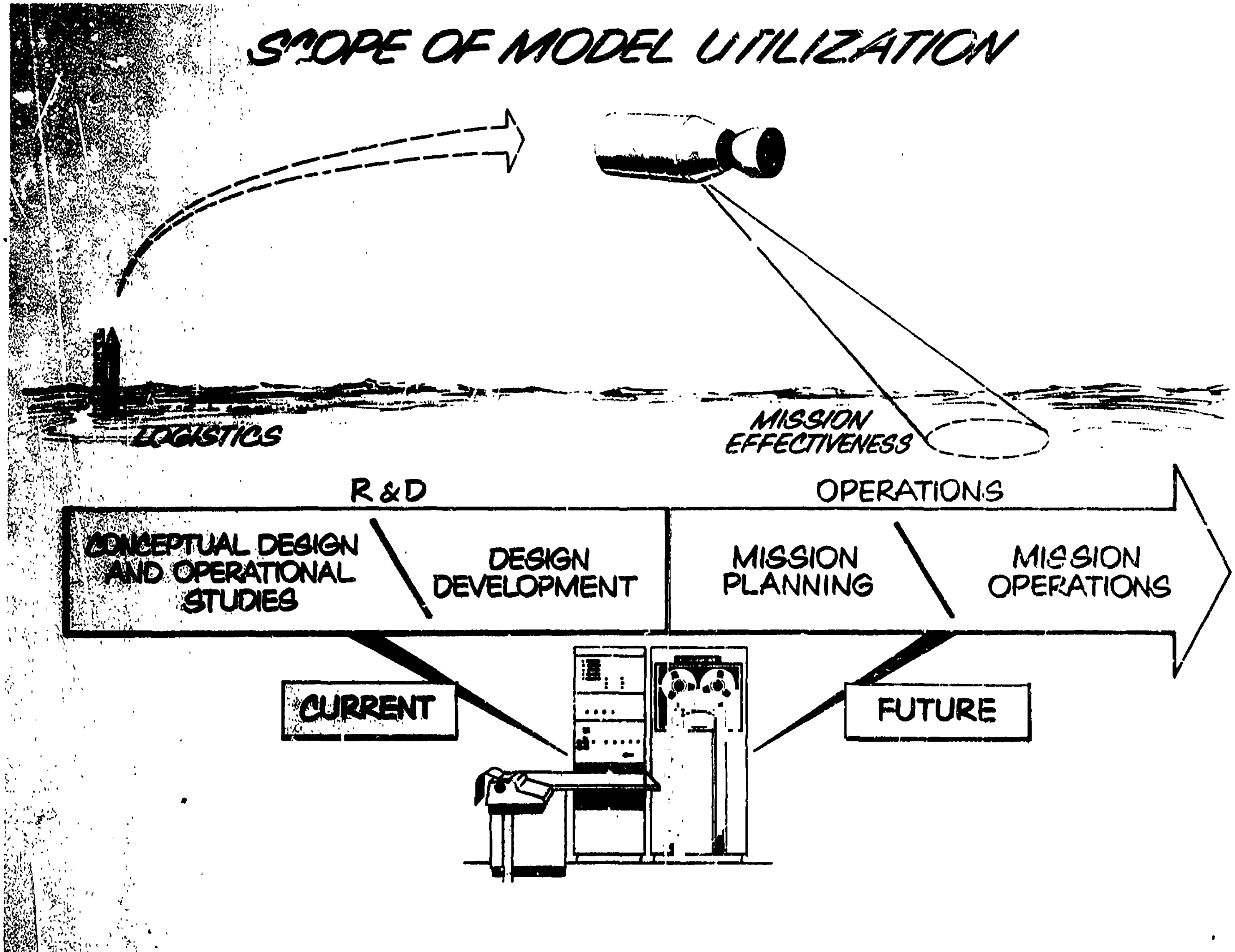

SCOPE OF MODEL UTILIZATION
LOGISTICS
MISSION EFFECTIVENESS
R & D
OPERATIONS
CONCEPTUAL DESIGN AND OPERATIONAL STUDIES
DESIGN DEVELOPMENT
MISSION PLANNING
MISSION OPERATIONS
CURRENT
FUTURE

Figure 4-1

utilization, the simulated data will be replaced with live inputs. This evolutionary concept offers the advantages of beginning with a basic model which includes the major aspects of the overall problem and can be extended in detail as the space station approaches its operational phase.

4.3 Model Utilization Requirements

The response times and accuracy requirements of the Space Station Model will vary with the utilization objectives as indicated in Figure 4-2. During the early phases of model utilization, input data may be difficult to obtain and much of the data, particularly contingency type data, must be estimated. Only moderate accuracy is required in these estimates and response time demands, at this stage, are considerably more lax than they will be in later program stages.

As the space station design reaches the development and test phase, higher accuracy will be required for the model. By that time, however, data should be available for actual systems tests, mock-ups, simulations, etc. In addition, the space station design will have acquired some firmness so that the acquisition of the problem input variable values will require less time.

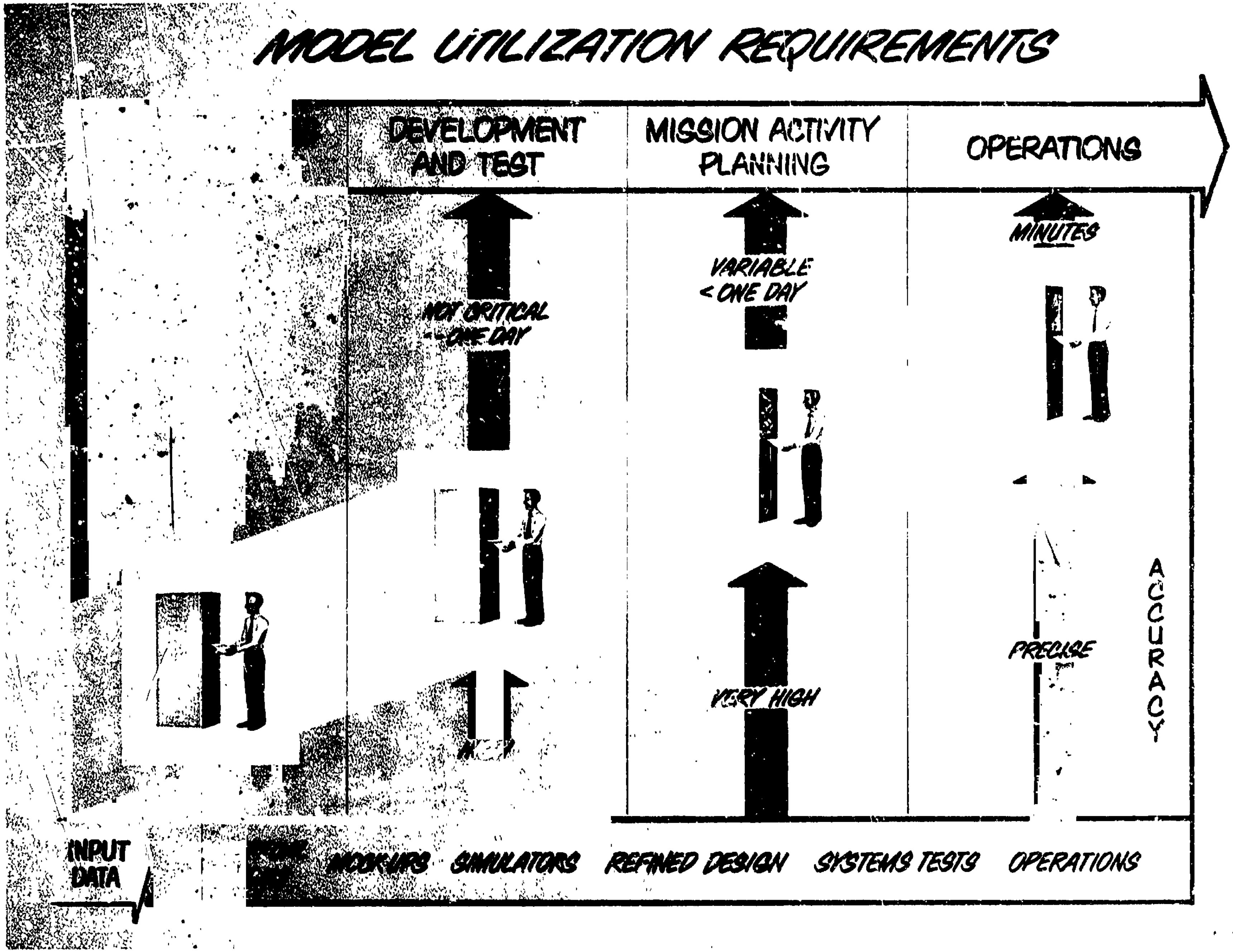

MODEL UTILIZATION REQUIREMENTS
DEVELOPMENT AND TEST
MISSION ACTIVITY PLANNING
OPERATIONS
MINUTES
VARIABLE
< ONE DAY
NOT CRITICAL
~ONE DAY
VERY HIGH
PRECISE
ACCURACY
INPUT DATA
MOCK-UPS
SIMULATORS
REFINED DESIGN
SYSTEMS TESTS
OPERATIONS

Figure 4-2

When the designs are refined and the space station program progresses into the operational phase, actual data will be available for mission control and, hence, both the high accuracy and response time requirements can be satisfied. This changing emphasis in time and accuracy has been recognized in the early stages of model development, so that the model can evolve along with the program and meet these requirements without extensive modifications to the basic structure.

4.4 Utilization of Model Output

The need for decisions will exist in all phases of the space station program - from design to operations. Access to the space station model will allow management to establish the consequences of the alternative courses of action prior to making the decision. This will allow selection of the best course of action consistent will available information.

The nature of the decision to be made, precision and accuracy requirements, and the admissible response time for the decision are necessary characterizations to the formulation of management's response, as shown in Figure 4-3. Once the factors describing the decision needed are specified, the decision-maker can evaluate the

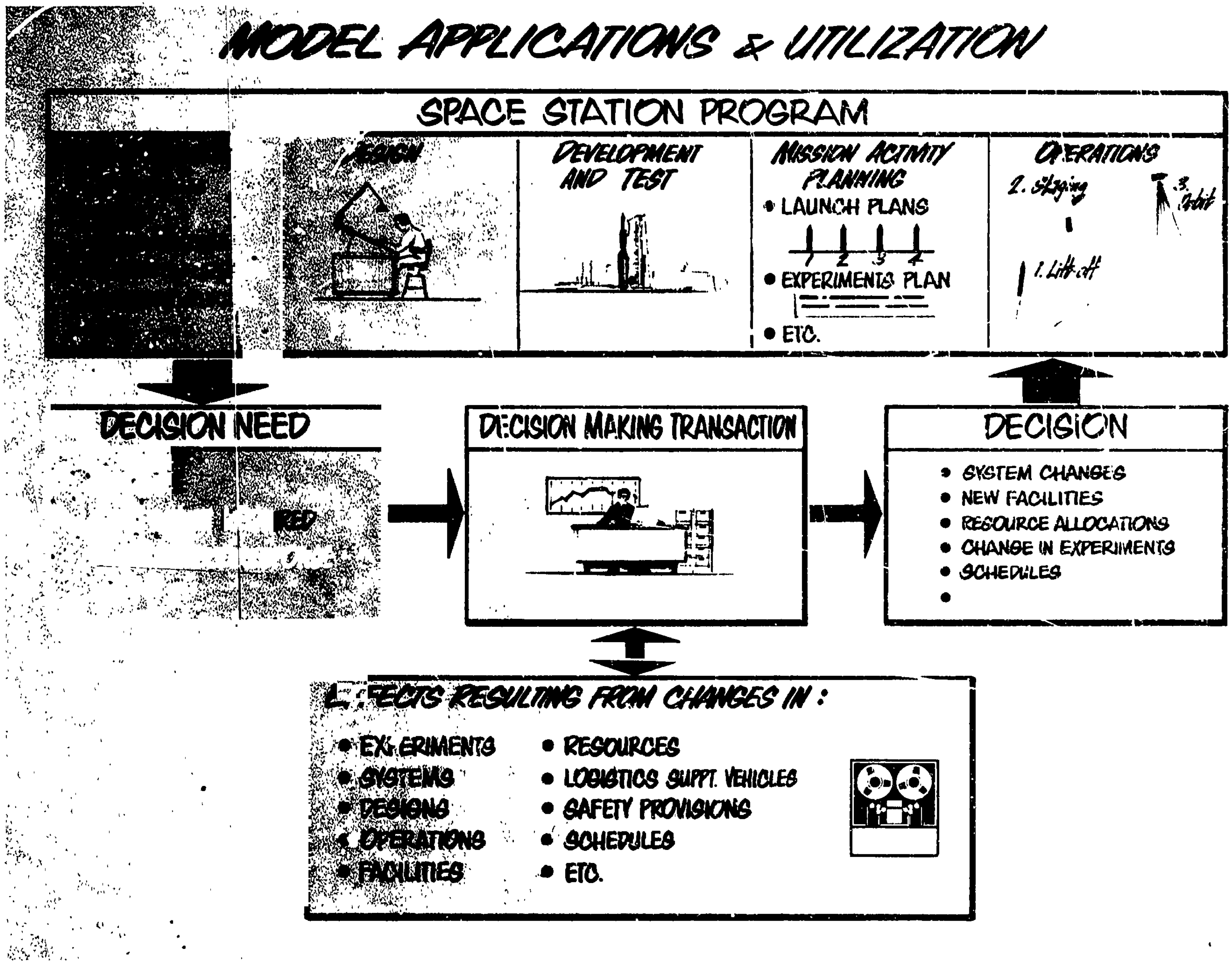

MODEL APPLICATIONS & UTILIZATION
SPACE STATION PROGRAM
DESIGN
DEVELOPMENT AND TEST
MISSION ACTIVITY PLANNING
• LAUNCH PLANS
1 2 3 4
• EXPERIMENTS PLAN
• ETC.
OPERATIONS
2. Staging
3. Orbit
1. Lift-off
DECISION NEED
DECISION MAKING TRANSACTION
DECISION
• SYSTEM CHANGES
• NEW FACILITIES
• RESOURCE ALLOCATIONS
• CHANGE IN EXPERIMENTS
• SCHEDULES
EFFECTS RESULTING FROM CHANGES IN:
• EXPERIMENTS
• SYSTEMS
• DESIGNS
• OPERATIONS
• FACILITIES
• RESOURCES
• LOGISTICS SUPPT. VEHICLES
• SAFETY PROVISIONS
• SCHEDULES
• ETC.

Figure 4-3

available alternatives and proceed to a decision. The model is called into use to determine the consequences of various alternatives, although management retains the responsibility for the final decisions. The element which is changed through use of the model is the degree of uncertainty within which management functions.

4.5 Typical Model Applications

Many of the space station considerations are interacting and must be evaluated as an entity. These are depicted in Figure 4-4. A primary application of the model is to determine the relationships between various experimental groups and station resources, crew skills mixes, logistics cost, etc. By using the model to process the possible programs, an effective balance of experimental return and available resources may be established.

A typical problem might be to develop a logistics schedule which would provide the necessary crew skills, station supplies, and experimental equipment to complete a planned experimental program with a minimum number of launches. To accomplish this, effective use of available experimental man-hours must be made by proper experiment scheduling while observing constraints such as crew skill and station resource availability.

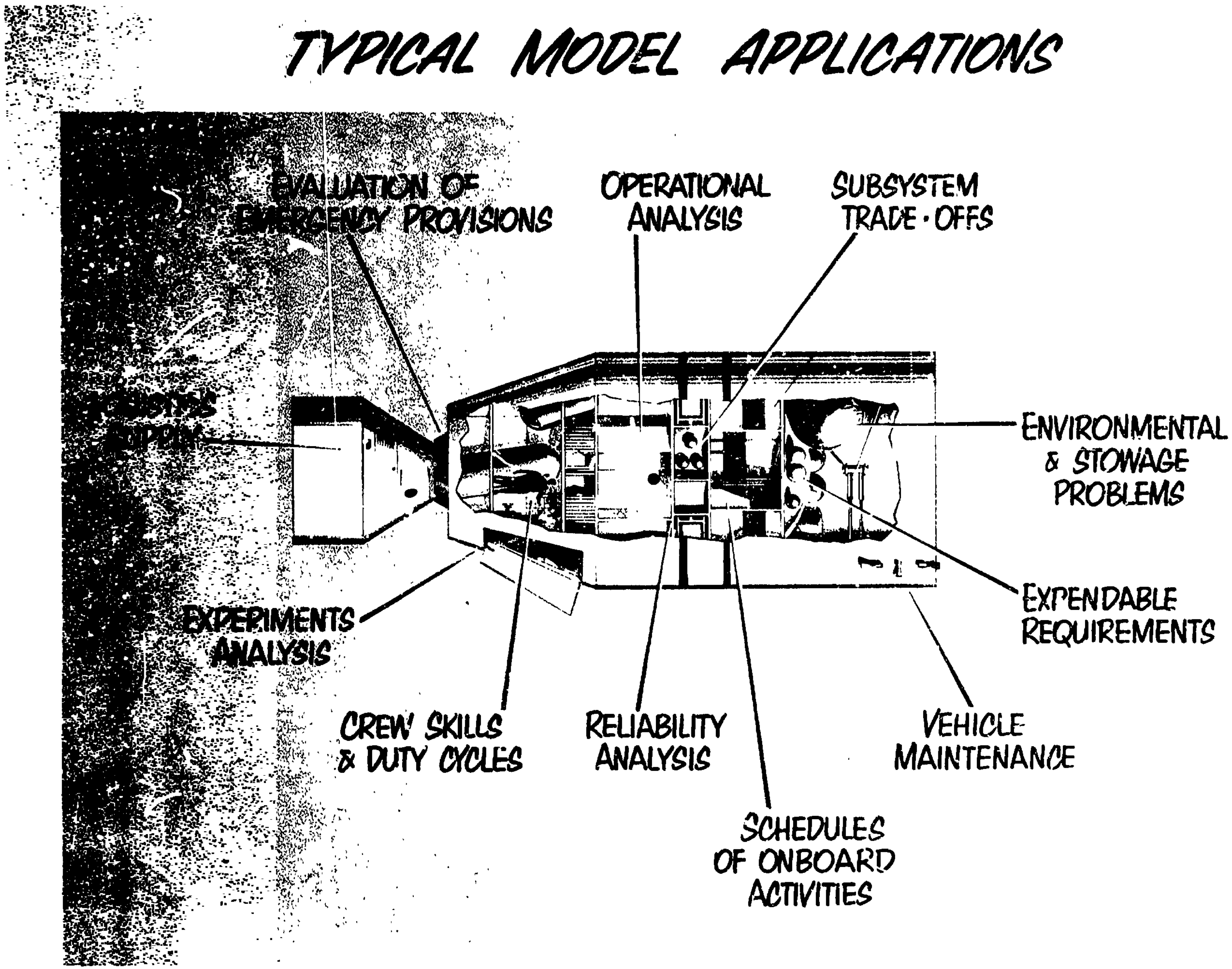

TYPICAL MODEL APPLICATIONS
EVALUATION OF EMERGENCY PROVISIONS
OPERATIONAL ANALYSIS
SUBSYSTEM TRADE-OFFS
ENVIRONMENTAL & STOWAGE PROBLEMS
EXPENDABLE REQUIREMENTS
VEHICLE MAINTENANCE
SCHEDULES OF ONBOARD ACTIVITIES
RELIABILITY ANALYSIS
CREW SKILLS & DUTY CYCLES
EXPERIMENTS ANALYSIS

Figure 4-4

Another example, requiring a greater level of detail would be the study of spare parts inventories. Although on-board maintenance is consdered necessary, it is contingent upon having the proper spares available. Obviously, the number of spares that can be stored aboard the space station or supplied by the logistics vehicle is limited. The effects of various mixes of on-board spare parts on mission effectiveness could be measured by the Simulation Mode if the spare parts inventory were systematically varied.

4.6 Formulation of Study Problems

In general terms, the model is able to study problems which consider the effectiveness aspects of a medium-sized space station. Many of the problems can be resolved by using libraries supplied with the model, which greatly simplifies the input burden. These libraries have been prepared from MORL or MORL-related study reports. If the problem requires the use of other libraries, these may be substituted for those supplied with the model by following the instructions contained in the model instruction manuals.

Experiment-related studies may be viewed either from the standpoint of changes in experimental accomplishment due to differences in experiment programs, or from the standpoint of changes in experimental accomplishment due to differences in levels of resources necessary to the experiment program.

In the first instance, the model will accommodate up to one hundred and fifty experiments. Section 7.0 describes in detail the composition requirement for an experiment package which will utilize the capability of the Planning Mode or Simulation Mode. When using the PRM independently, only the total experiment hours, skill requirements, and total duration need be known.

An alternate set of experiments for study purposes may be derived through variations in an initial set of experiments, such as those provided with the model, or through the definition of a new set. Variations in an experiment set may occur through rearrangement of experiments (priority, investigational areas, etc.), deletions, additions, or revision of experiment requirements (descriptions).

The majority of the model structure was developed for resource management and accounting, and the most prominent resource consists of man-hours categorized by skill classification. The Preliminary Requirements Model (PRM) can evaluate the effects of varying the degree of crew specialization or it can appraise other factors which relate to crew versatility, or performance. These include crew rotation plans, overtime allowables, proficiencies, allowable shift lengths, and variations in crew size (up to nine men).

The crew skill and initial assignment philosophy factored into the preliminary analysis continues into the mission planning and simulation phases. In the mission planning phase, performed by the Planning Mode, additional crew-related factors are introduced. These are primarily related in an increase in scheduling detail in which checks are made to ascertain that the appropriate crew types and man-hours are available for the timely execution of an experiment. In the Simulation Mode, additional crew-related factors are considered including crew illnesses effects, contingency task assignments, task interruptions, and a more detailed consideration of overtime policy. Although the model is structured to select and efficiently utilize the crew, resource checks are made on power, communications, equipment, system outputs, and ten classifications of expendables. In the Planning and Simulation Modes, additional checks are made of resources utilized.

In its assessment of experimental accomplishment, the PRM considers an additional resource, the logistics payload capability (weight and volume) provided by planned logistic launches. The logistics routine is common to the PRM, Planning Mode, and the Simulation Mode. However, the consideration of unscheduled events, such as vehicle failures or launch delays, occurs only in the Simulation Mode. A discussion of the logistics routine is contained in Section 5 of this report.

Relationships between experimental accomplishment and resource utilization may be constructed in all phases of model operation. The inherent flexibility in changing resource levels, policies, etc., enables the formulation of many problems of a parametric nature. The parameters and the manner in which they are considered in the model are discussed in more detail in subsequent sections of this report.

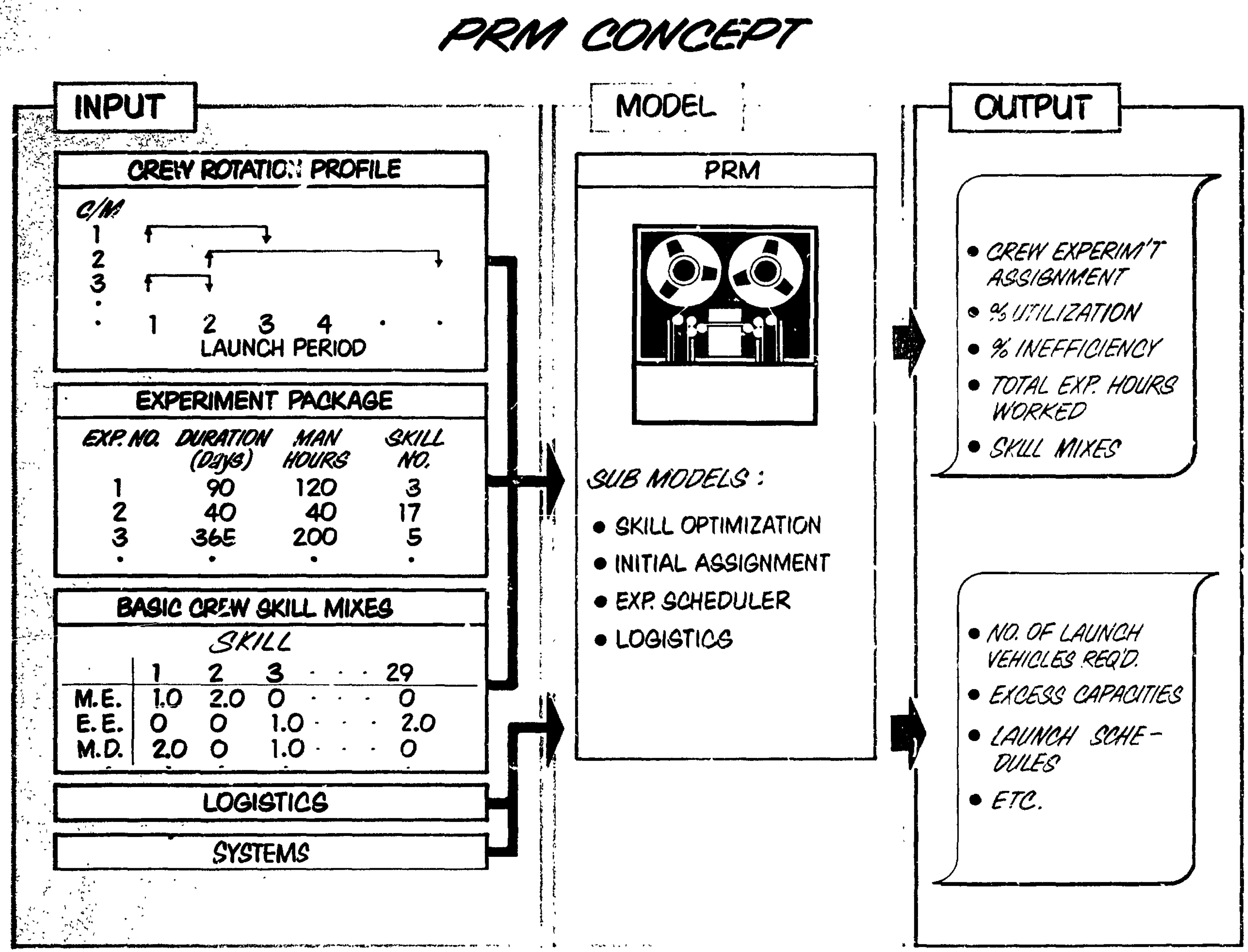

PRM CONCEPT
INPUT
CREW ROTATION PROFILE
C/M
1
2
3
1 2 3 4
LAUNCH PERIOD
EXPERIMENT PACKAGE
EXP. NO. DURATION (Days) MAN HOURS SKILL NO.
1 90 120 3
2 40 40 17
3 365 200 5
BASIC CREW SKILL MIXES
SKILL
1 2 3 . . . 29
M.E. 1.0 2.0 0 . . . 0
E.E. 0 0 1.0 . . . 2.0
M.D. 2.0 0 1.0 . . . 0
LOGISTICS
SYSTEMS
MODEL
PRM
SUB MODELS:
• SKILL OPTIMIZATION
• INITIAL ASSIGNMENT
• EXP. SCHEDULER
• LOGISTICS
OUTPUT
• CREW EXPERIM'T ASSIGNMENT
• % UTILIZATION
• % INEFFICIENCY
• TOTAL EXP. HOURS WORKED
• SKILL MIXES
• NO. OF LAUNCH VEHICLES REQ'D.
• EXCESS CAPACITIES
• LAUNCH SCHEDULES
• ETC.

Figure 5-1

5.2 Model Operation

5.2.1 Input Requirements

The PRM input data consist of information describing the experimental program, the crew rotation plan, crew skills, available crew time, and mission logistics requirements. The experimental tasks are defined in terms of duration, total man-hours, and skill requirements. The model recognizes 20 different scientific skills which may be defined to suit problem requirements, as well as 13 subject specifications. These subject specifications provide a means for assigning an experimental task to a particular crewman or group of crewmen. The proficiency of a crewman in a given skill is indicated by means of a task time factor, i.e., a number which, if multiplied by the man-hours required by an experiment, will yield the number of man-hours this crewman will expend in working the experiment. In the crew rotation plan, the model user specifies the crewman who is to occupy each crew position on the space station during each launch interval (the interval between consecutive crew deliveries), and the particular set of skills each crewman is to possess. (The latter is optional, the Skill Optimization Routine will make this assignment of skills, if desired.) The model is limited to crew sizes of no more than nine men and missions involving no more than 30 men. The inputs which control the available crew time consist of a specification of the nominal daily working hours for each crew position and parameters which determine the constraint on over-time work (work in excess of the nominal working time). If logistics considerations are desired, the logistics requirements of the mission and parameters describing the logistics vehicles and launch facility are input.

5.2.2 Operation

Once the input data have been read in, the model converts the experiments into a set of tasks, each requiring a crewman with a specific skill for a stated number of hours each day over a defined span of mission days. Similarly, the model determines what experiments are on board the station and eligible for scheduling at the beginning of each launch interval.

The list of experimental tasks for each launch interval is examined to determine what portion of each task may be assigned to a crewman during that interval. This assignment is made subject to the constraints imposed by the crew-time available as well as the skills of the crew on board during this launch interval. If the skills possessed by a crewman have not been specified, the model will assign a set of skills to this man before the experiments are scheduled. This process is repeated for each launch period until the end of the mission is reached.

5.2.3 Model Outputs

The PRM prints out the results of the scheduling of the experimental work for each launch interval considered during the mission. This output includes a list of the experimental tasks assigned to each crewman, the total hours worked by each crewman, and the work remaining on each of the tasks. It also includes a number of effectiveness measures such as the fraction of the total experimental work completed and the fraction of the available crew time utilized. Also, upon completion of the mission, a summary of the results of the entire mission is printed out. This summary includes a list of the tasks assigned to each crewman involved in the mission, the hours worked by each crewman, and the skills assigned to each crewman; it also includes a print out stating the fraction of the experimental work accomplished.

In addition to this printed output, the PRM has the capability for generating four of the data library decks used as inputs in the Planning Mode. This feature allows the model user to run the same problem on the PRM and in the Planning Mode without extensive coding of PRM results for Planning Mode input.

5.3 Scheduling Procedure

The scheduling routine within the PRM is capable of approximating the refined scheduling performed in the Space Action

Simulation Model. The quality of the output data is adequate for broad planning analysis. The scheduling technique incorporated in the PRM was designed to satisfy the following conditions:

1. Short computer run time
2. Recognition of key experiment parameters
3. The capability to schedule experimental tasks for each crewman so that each crewman will have the capability to work "overtime" as well as observe specified nominal constraints of allowable hours per day.

In order to achieve these qualities, the following approach was taken. The key experiment scheduling parameters are the duration of the experiment and the total man-hours required. Realistically, there may be an unequal distribution of work activity over the duration, e.g., cyclic work and interspersed periods of inactivity. To consider these factors would, however, compromise the first computer model requirement, short run time. Scheduling is accomplished by use of simple experiment descriptors to obtain an average and constant work activity, i.e., smooth out the experiment work distribution. Each experiment then becomes a simple rectangle, the length of which is the duration and the height of which is the average hours required per day. Geometric techniques can then be employed to simulate experiment scheduling.

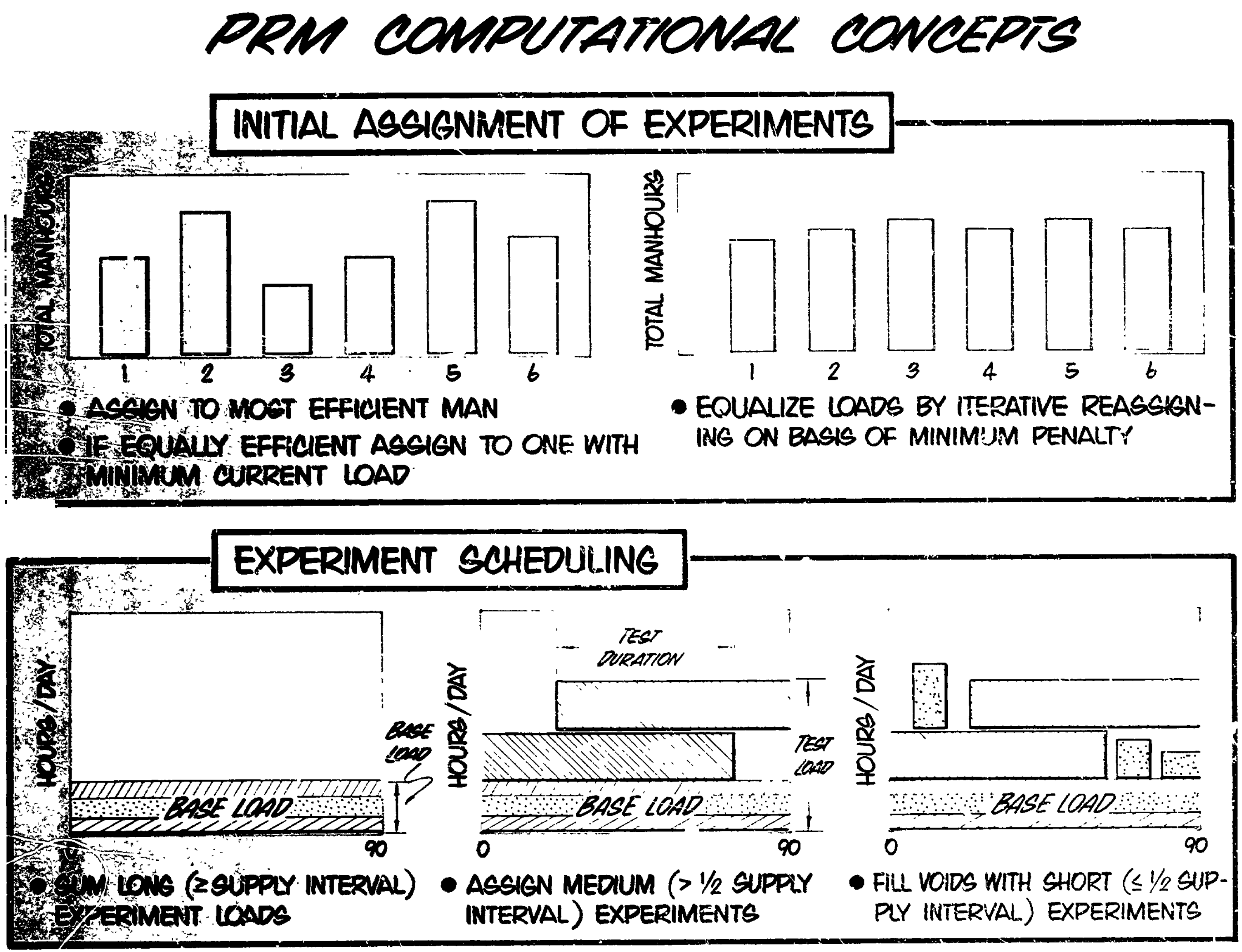
The scheduling routine is capable of scheduling experiments singly (when it is desirable to arrange experiments by priority) or by batch (when it is desired to schedule experiments without priority considerations). When batch scheduling is used, the initial experiment assignment scheme must be relatively insensitive to the order of the experiment list and relatively unperturbed by the scheduling submodel. The procedure followed in scheduling according to these two policies are discussed below.

5.3.1 Scheduling Without Priority

When scheduling without priority, the objective is to achieve the best utilization of available crew time. The method consists of two basic steps:

1. The model makes an initial assignment of experiments to crewmen on the basis of skill alone, without regard to work load constraints.
2. The model manipulates this initial assignment, attempting to satisfy the work load constraints.

A set of heuristic rules, depicted in Figure 5-2, was developed to permit rapid experiment assignments with no constraints on the crew workloads. These rules, which are relatively insensitive to the order of experiments, result in rapid, efficient assignments, but not necessarily the optimum assignments. The rules are set forth below:



PRM COMPUTATIONAL CONCEPTS
INITIAL ASSIGNMENT OF EXPERIMENTS
TOTAL MANHOURS
1 2 3 4 5 6
• ASSIGN TO MOST EFFICIENT MAN
• IF EQUALLY EFFICIENT ASSIGN TO ONE WITH MINIMUM CURRENT LOAD
TOTAL MANHOURS
1 2 3 4 5 6
• EQUALIZE LOADS BY ITERATIVE REASSIGNING ON BASIS OF MINIMUM PENALTY
EXPERIMENT SCHEDULING
HOURS/DAY
BASE LOAD
BASE LOAD
90
• SUM LONG (≥ SUPPLY INTERVAL) EXPERIMENT LOADS
HOURS/DAY
TEST DURATION
TEST LOAD
BASE LOAD
0
90
• ASSIGN MEDIUM (> ½ SUPPLY INTERVAL) EXPERIMENTS
HOURS/DAY
BASE LOAD
0
90
• FILL VOIDS WITH SHORT (≤ ½ SUPPLY INTERVAL) EXPERIMENTS

Figure 5-2

1. Assign the first experiment to the "best" crewman (smallest task time factor for the required skill).
2. Continue to assign experiments until all experiments have been assigned. If more than one crewman qualifies as "best," assign the experiment to the man whose current load (total of assigned experiment man-hours) is lowest.
3. Determine the average total man-hours of experimental tasks per crewman (ratio of total experiment hours in package to the total number of crewmen).
4. The work loads of the crewmen are equalized by, first, finding the crewman with the largest work load, then searching his experiment list to determine which experiment will reduce his load the most (but not below the average) and when reassigned will incur the least penalty (minimum task time factor). The only crewmen considered as candidates for the reassignment are those whose workload is currently below the average load.

The capability of the above scheme to provide consistent results for all arrangements of the experiment queue has been experimentally verified through extensive model exercising.

Once the initial assignment of experiments has been made, the experiments are divided into three categories - long, medium and short - according to the duration of the experiment. The program then attempts to fit the experiments within the work load constraints using the geometric technique illustrated in Figure 5-2. The procedure used is as follows:

1. The long experiments (duration greater than or equal to the length of the launch interval) are assigned to a crewman and total hours per day are summed to obtain the "base load."
2. The medium experiments (duration less than the length of the interval but greater than one-half this length) are arranged by descending duration (longest first) along with the alternatives, the first one from the start of the interval and the next one from the end of the interval. This creates an area of overlap in the center of the interval.
3. The short experiments (duration less than one-half the length of the launch interval) are then used to fill in the "gaps" around the medium experiments.

After each step in this process is completed, a test is made to assure that the allowable hours per day and overload constraints (input data for each crew member) have not been exceeded.

As experiments are rejected on the acceptable work load test, they are removed from the crewman's list and temporarily stored. Assignments to all crewmen are processed in a like manner. The next step is to process the list of experiments that were temporarily stored as unworkable to determine if some of the experiments can be accepted by other crewmen. The residual experiments are stored as "unscheduled."

5.3.2 Scheduling with Priority

When the scheduling with priority option is used, the priority is determined by the order in which the experiments are arranged in the experiment package. The first experiment in the package has the highest priority. The program logic for cases with priorities is described below:

1. The first experiment is assigned temporarily to the most proficient crewman. This experiment is scheduled along with those previously assigned to the crewman. If a constraint is exceeded, the experiment under consideration is reassigned; otherwise, the experiment remains assigned to that crewman.
2. If reassignment is necessary, a search is made for the next best (proficiency test) crewman, and an attempt is made to assign the experiment to him.
3. If no crewman can accept the experiment, it is stored as an unscheduled experiment.
4. Each experiment on the list is processed through the preceding series of operations.

5.4 Interface with Other Major Logic Elements

5.4.1 Logistic Considerations

The description of the logistics submodel is presented in Section 8.0. The Preliminary Requirements Model utilizes the logistics submodel to obtain (1) the excess capacity of the logistic vehicles (this determines the number of new experiments which can be brought up to the space station) and (2) the length (duration) of each launch interval. The PRM work assignments start at that point in the mission when the space station has been checked out, fully staffed, and is ready to begin the experimental program. Through the input data, the model user specifies the number of launches. The excess capacities (weight and volume) are input into the PRM which determines the cumulative sum of the weight and volume associated with each experiment. When the sum of either the experiment weight or volume exceeds the excess capacity, the experiment list is terminated. This is accomplished for each launch interval.

5.4.2 Crew Skill Optimization

An integral part of the PRM is the assignment of scientific skills to the crewmen so as to achieve the best utilization of the available crew time. The process is described in detail elsewhere in this report. The submodel performs an initial screening of various combinations of skill mixes (i.e., combinations of skills which one man may reasonably be expected to possess), eliminating those that are obviously unsatisfactory. The remaining candidate combinations are each sent through the previously described scheduling process so that a primary number and a secondary merit number are generated for each candidate combination. These merit numbers are essentially the adjusted experimental hours worked (primary) and the inefficiency of work (secondary - used when primary merit numbers are equal). The particular skill mix combination with the highest primary merit number is then returned to the main program as the chosen crew. The PRM then performs all the previously discussed operations (assignment, scheduling, etc.) in accordance with the options desired by the model user.

6.0 CREW ANALYSIS

6.1 Introduction

Crew related factors affect all phases of model simulation and, hence, appear throughout the model and its associated libraries. The selection of crews on the basis of skills and skill cross-training considerations, along with initial crew task assignments, are performed in the Preliminary Requirements Model (RPM). In the Space Station Model Planning Mode, experimental tasks and station operations tasks are scheduled for each crewman. Task time factors may be used, in the Space Station Model or PRM, to adjust man-hour requirements whenever assignments are made to crewmen who do not possess the primary skills dictated by the tasks.

A more elaborate management of crew related factors is performed in the Simulation Mode of the Space Station Model. Consideration is given to the probabilistic task completion times, occurrences of various degrees of illnesses, selection of crews for unscheduled repairs, monitoring of crew safety and crew status, and extended shift lengths under certain conditions. Numerous other crew factors may be studied through input options such as crew rotation frequency and number of crewmen in the station.

In addition to these primary considerations, the influence of crew factors on rate and degree of accomplishment is inherent in numerous other relationships within the model or its library. These are exemplified by policies of task sharing and limited reassignment. A length compilation of descriptive information is available as output depicting the crew and its role in respect to the mission.

Because of the profound importance of crew consideration on the model and the results obtained, considerable attention has been given to the investigation and formulation of suitable relationships and model structure. Specialists were called upon to supply additional information in areas when data deficiencies existed. The results of these investigations and the subsequent actions taken in model development are discussed in this section.

6.2 Crew Performance

Several human factor analyses concerning crew performance in a space station environment were conducted during the study. The data and conclusions drawn from these analyses were further investigated to determine which factors significantly influence the model's overall effectiveness measures and should therefore be included in the structure. In this manner, the level of detail concerning crew performance was made consistent with the remainder of the model and a proper balance was maintained. These crew performance analyses and modeling concepts are described in detail in the remainder of this section.

6.2.1 Long Term Overloaded Schedules and Recovery Requirements

In past studies, few efforts, if any, have been made to vary the length of the work period systematically over a wide range of values such as would be required to derive a function relating crew productivity over the duration of a period of extended work schedules. In most of the studies consideration was given to a fixed length of the work period and the total amount of work required in 24 hours.

Numerous other factors must be considered: (1) the length of the work period, (2) the length of the rest period, and (3) the ratio of work to rest in a 24-hour period. The problem is further complicated by the fact that crew efficiency is subject to diurnal variations (where the work-rest cycle is not coincident with the normal 24-hour cycle) that may mask or confound the variation due to length of duty period alone. None of the data reviewed provided a direct derivation of the desired function; however, some inferences can be drawn from available data.

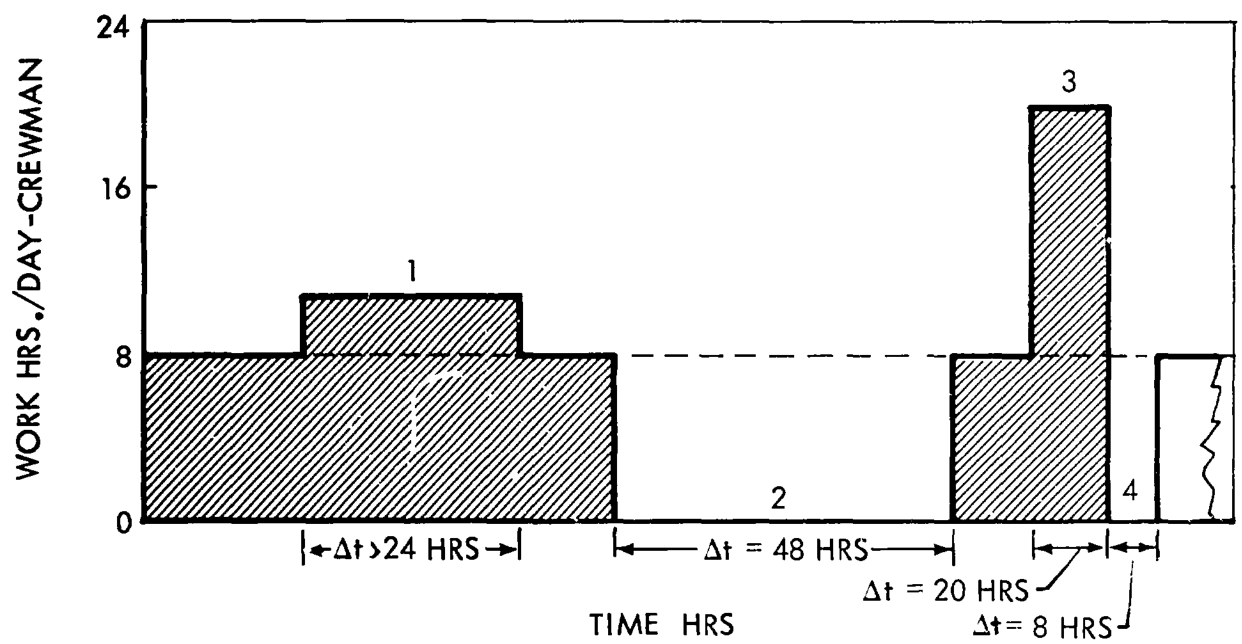
In one of the earliest studies (Ref. 1), the performance of 16 subjects was measured over a period of 96 hours on four different cycles of work hours followed by rest hours: 2-2, 4-4, 6-6, and 8-8. It was evident that the subjects could work at the tasks assigned without loss of efficiency for a total of 12 hours per day for at least 96 hours. In a second series of studies, subjects followed a schedule of either four hours of work and four hours of rest or a schedule of six hours of work and two hours of rest. The results from these tests indicate that severe decrement in performance would probably have resulted from prolongation of the 6-2 schedule beyond the 96 hours of testing. The findings from this series of tests may be summarized as follows:

1. Subjects working 12 hours per day on a 4-hour work and 4-hour rest schedule are able to maintain their performance at a higher level than subjects working 16 hours per day on a 4-hour work and 2-hour rest schedule. The 4-4 schedule can probably be followed from 60 to 90 days without decrement in performance.
2. The imposition of a period of sleep loss will result in significant performance decrements. Performance returns to approximately the level that would be expected had there been no period of sleep loss after the subjects on the 4-4 schedule have had two sleep periods (eight hours) and those on the 4-2 schedule have had three sleep periods (six hours).

These data, cited from the most comprehensive study of work-rest cycles to date, are difficult to apply to the questions at issue in model construction, i.e., duration permissible for overload schedules and recovery requirements. The reason, of course, is that in the baseline MORL work-rest cycle it is assumed that each astronaut is allowed 8 hours of uninterrupted sleep. In the studies summarized in Ref. 1, on the other hand, subjects on the 6-2 schedule averaged less than 4 hours of sleep a day, while the subjects on the 4-2 averaged about 5.5 hours per day. Assuming that a similar ratio of approximately 4 hours of sleep in each 6 hours of "rest" holds for the later studies (the authors are not specific on this point) it might be assumed that the subject on the 4-4 schedule received approximately 8 hours of sleep each day, while the subjects on the 4-2 schedule received about 5.3 hours a day.

If the additional assumption is made that the overloaded schedules which may result from a MORL contingency are accomplished by a reduction in the sleep period, certain conclusions are permissible:

1. A reduction in the sleep period from 8 hours to 5.3 hours can be made for at least 15 days without any significant degradation in performance efficiency, as shown in Figure 6-1.
2. Recovery from a period of 40 hours of continuous work can be expected after two additional sleep periods occurring at the normal time.



	EVENT	TIME SPAN
1	LONG TERM OVERLOAD	INDEFINITE
2	MINOR ILLNESS	48 HOURS
3	SHORT TERM OVERLOAD	LESS THAN 20 HOURS
4	OVERLOAD RECOVERY PERIOD	8 HOURS

Figure 6-1 WORK TIME AVAILABLE FOR CREWMAN

As a result of these conclusions, logic for a temporary reduction in the sleep period of 2.7 hours/day/crewman has been included in the model structure to absorb peak demands generated by the contingency tasks generated by the model operating in the Simulation Mode. By using this reduced sleep period in lieu of rescheduling, the model attempts to maintain the original mission plan derived in the Planning Mode. Tasks are rescheduled only when these extra daily man-hours are insufficient to satisfy the demands. No set of contingency tasks could be found which would require either a 15 day overload period or 40 hours continuous work for any one crewman without prior mission abort, hence, these restrictions were omitted in the interest of modeling simplicity.

6.2.2 Short Term Overload

In peak load periods, crew workshifts could be temporarily extended. A considerable amount of research has been directed toward the problem of determining the optimum work-rest cycle for long duration space missions and orbital space stations. It should be evident, however, that the applicability of these data to the actual conditions to be encountered is speculative. Data obtained from the Mercury and Gemini programs to date are only suggestive with respect to the routines and work durations appropriate for an orbital station such as the MORL. The following major differences make a direct comparison difficult:

1. Size of crew

2. Volume of spacecraft

3. Duration of mission

4. Objectives of mission.

Experimental data obtained from numerous space cabin simulation and work-rest cycle studies (summarized in Reference 1, 2, 6 and 7) probably represent the best source of information for estimating the effect of extended work periods on crew efficiency in the space station. The following assumptions must be made, however, if these data are to be used:

1. The test subjects used in the simulation studies are comparable to the MORL astronauts in performance capability.

2. Weightlessness and other environmental factors unique to the MORL are not significant determinants of crew efficiency.

3. The performance tests used in the simulation studies are equivalent to the tasks required of the crew in the MORL.

It has been emphasized by several of the researchers in this field that the primary factor in selecting the duration of the duty period is the nature of the activity. As reported in Reference 2, in general, where a passive task such as radar-scope monitoring is involved, a loss of efficiency may be noticed after as little as

2 hours of continuous duty. When a passive task is combined with one or more active tasks, the duty period may be extended to 4 hours without appreciable loss of efficiency. Duty periods may be routinely extended to 8 to 10 hours if the major tasks call for active participation and there is considerable variety in the tasks. Duty periods requiring relatively continuous performance for periods longer than 10 hours are likely to require that crew members exert increasing effort in order to avoid lowering performance standards. Data reported in Reference 7 indicate that on a task comprised of monitoring several simulated aircraft indicators, the initial level of proficiency was maintained for about 16 hours before a gradual reduction in efficiency was noted. In another study involving a complex operation task, a reduction was noted after 15 hours.

None of the studies reviewed provides a clearcut answer to the question of the characteristics of the function relating efficiency to shift length. In a typical curve, a constant level is maintained for about 10 hours and is followed by a gradual but irregular decline. Since the study is typically terminated far above the point of complete physical and mental exhaustion, it is not known whether the rate of decline is linear or accelerates with time.

For modeling purposes, it could be assumed that performance level is constant for 10 hours, followed by a 50 percent loss of efficiency after 20 hours with recovery after 8 hours of uninterrupted rest. This is illustrated in Figure 6-1. Should more than two such extended work periods be required, it may be advisable to use the more conservative long-term overload cycle described in subsection 6.2.1. Since the model is constructed to examine all work assignments on at least a daily basis, considerable flexibility is inherent in the treatment of allowable overloads through the selection of shift lengths and task time factors. Automatic degradation of efficiency was not included in the model in order to avoid undue modeling complexity which would result in only minimal increased overall accuracy.

6.2.3 Estimates of Earth-to-Orbit Task-Time Ratios

One of the purposes of the model is to perform sensitivity analyses to provide insight into areas in which information is sparse, such as estimating earth-to-orbit task-time ratios. An analysis of available data was conducted in an effort to establish a correlation between the time required to accomplish a task on earth and the time required to accomplish the same task in earth orbit as a point of departure with the model. These tasks were divided into two basic categories: intravehicular tasks and extravehicular tasks. As noted previously, data derived from simulated weightlessness and aircraft studies and from the Mercury and Gemini programs to date must be used with caution in estimating task times for an advanced space station such as the MORL. It would be reasonable to assume that the MORL astronauts will have sufficient time to adapt to the weightless condition in the "shirtsleeve" environment of the station and should learn to overcome any initial hesitancy, particularly in the larger body movements. For the activities that require fine control movements and finger dexterity, little if any performance decrement should be expected in the experienced astronaut. With respect to extravehicular activities, the available data are again inadequate since comparable tasks had not been measured at the time of this analysis. It is expected, however, that considerable improvement will be made in the mobility and manipulative dexterity of the pressure suit as well as in space maintenance technology.

Unfortunately, data from the later Gemini flights were not available at the time of this analysis. Experimental data relevant to the objectives of this analysis were obtained from the following sources:

1. Pressure suit mobility studies
2. Zero-g aircraft studies
3. Water immersion studies
4. Frictionless platform studies.

These data may be used for at least a rough estimate of the probable ratio of earth to orbit task times if certain simplifying assumptions are made:

1. Intravehicular tasks will be accomplished in a "shirt sleeve" environment.
2. Task times at 1-g and zero-g are equivalent in the "shirt-sleeve" condition after a period of initial adaptation.
3. Data on performance decrement obtained with Mark IV and Gemini suit pressurization under 1-g or simulated zero-g may be used to estimate the expected comparable decrement during EVA.

Data on the percentage loss of mobility in a pressurized suit derived from representative studies show a surprising amount of agreement. Burns et al. (Ref. 5) reports a 70 percent loss of mobility in the Mark IV suit; Pierce (Ref. 12) noted a 58 to 68 percent loss in the Gemini G-2-C suit; and Glazer (Ref. 8) concludes that it takes approximately 68 percent longer to perform maintenance in pressurized suits of state-of-the-art design (International Latex and Gemini G-1-C). It is interesting to note, in passing, that the decrement in mobility appears to be equivalent to the decrement in time-to-accomplish, although more data would be required to establish this as a valid generalization.

A high degree of agreement is also reflected in the reports on the decrement associated with an unpressurized suit as compared to the shirtsleeve condition. Simons (Ref. 4) found that suited motions in the zero-g trajectory required approximately 30 percent more time than unsuited motions; Pierce (Ref. 12) reports a 23 percent loss in mobility; and Glazer (Ref. 8) found that it took 42 percent longer to perform maintenance in the unpressurized suit. In a study of space maintenance techniques, Seale (Ref. 13) summarizes the available data on extravehicular space maintenance by forecasting a 100 percent increase in maintenance time. This figure is also supported by Peters and Mitchell (Ref. 11) in a study comparing times to accomplish maintenance on a J2 engine in the pressurized and unpressurized suit conditions.

For modeling purposes the following conclusions were made with respect to earth-orbit task time ratios:

1. No degradation in time is assumed for intravehicular tasks in a shirtsleeve environment over comparable tasks under 1-G environment.
2. A 100 percent increase in time is assumed for extravehicular tasks over comparable tasks under 1-G conditions.

These task time ratios are reflected in the station operational and experimental task-time estimates included in the model's library and input data decks. These estimates can be revised as desired by the model user as new data become available.

6.2.4 Estimates of Manual Package Handling Requirements

It is evident that objects within a space station have no "weight" as this term is normally defined, and thus there is theoretically no limit to the weight that a crewman can lift. The practical limitations upon the weights and volume that may be easily handled are, however, an important consideration. In general, the factors that would limit size and volume of packages are: (1) mass or earth "weight" of the object, (2) size or volume, (3) shape, (4) provisions for grasping, and (5) number of crewmen.

The mass of an object in space becomes significant only when it is great enough to create a problem, i.e., when it requires great force to move the object or great counterforce to stop movement. These factors, in turn, are significant only in relation to the distance involved and the time available. If the mass is large in proportion to the mass of the man (or men) moving the object, the application of a pushing or lifting force to such a "heavy" object might result in the displacement of the mover or perturbation of the spacecraft.

Size or volume of an object is important only if the object is too large to be grasped conveniently, in which case several crewmen might be required. Similarly, shape is important with respect to difficulties that might be encountered in maintaining a firm grasp. If large cumbersome objects are to be moved about by the crew, it would be desirable to make special provisions for grasping to prevent the object from floating away or damaging other equipment, e.g., the handling fixture provided for the MORL IIb power conversion units. If the object is large and cumbersome, a single crewman might find his view blocked and have difficulty estimating when to apply the counter force needed to bring the object to rest. He might also experience problems of angular momentum with large objects where the center of mass is considerably displaced from the convenient points for grasping. Under these conditions the assistance of a second crewman would be almost essential.

From these observations of the factors which would limit the size and volume of packages to be handled by crewmen two general conclusions were drawn:

1. In most cases a single crewman should be capable of moving any size object that would conceivably be placed within a space station. If the object is large enough to block the crewman's view, is poorly

designed for grasping, or of such a great mass that its momentum might represent a hazard to the station or crew, two crewmen should be able to handle the object easily and safely.

2. Since objects within a space station have no weight, there is no convenient "rule of thumb" for determining the maximum mass or volume that can be safely lifted by one or more crewmen.

Where possible, these conclusions have been utilized in estimating the crew requirements for performing major module replacements and bulk cargo handling. However, most of the packages were not defined in sufficient detail to allow even a rough assessment of sizes; therefore, one man was usually assumed to be capable of performing all tasks. This simplification is not expected to cause significant decline in accuracy, since the number and frequency of these type tasks per mission, or even per resupply interval, are comparatively low. However, this is an area suggested for further study in the future.

6.3 Crew Skill Analysis

6.3.1 Introduction

One of the more important areas of representation in the model is that of specifying crew skill mixes. The efficiency with which the crew is utilized is particularly sensitive to the skills available, since many experiments require special skills to be performed.

The first objective set forth in the crew skill analysis was to develop a procedure for specifying a highly efficient crew based on skill cross-training considerations. Because of the limited amount of data describing the type and degree of cross-training a crewman may be expected to possess, as well as the subjective nature of this type of assessment, it is mandatory that the procedure permit a great deal of flexibility in setting feasible skill mix types. The second objective was to develop a matrix of feasible skill mixes to be used with the procedure. The crew skill optimization procedure, discussed on the following pages, was integrated into the Preliminary Requirements Model (PRM). The results obtained in the PRM are then input into the Space Station Model as library.

6.3.2 Crew Skill Optimization Procedure

The crew time requirements for performing the scientific experiments are expressed in terms of man-hours of certain scientific and technical skills. In the case of the baseline scientific experiments formulated for the MORL, 20 skills have been identified:

1. Biological Technician
2. Microbiological Technician
3. Biochemist
4. Physiologist
5. Astronomer/Astrophysicist
6. Physicist
7. Nuclear Physicist
8. Photo Technician/cartographer
9. Thermodynamicist
10. Electronic Engineer
11. Mechanical Engineer
12. Electromechanical Technician
13. Medical Doctor
14. Optical Technician
15. Optical Scientist
16. Meteorologist
17. Microwave Specialist
18. Oceanographer
19. Physical Geologist
20. Photo Geologist

These skills are presently included in the model library; however, any alternate set may be used with the skill optimization procedure described in this section. The objective of the skill optimization procedure is to select crew members, based on their possession of certain skills, in such a manner that the available crew time will be utilized most effectively in the experiment program.

The principal source of difficulty in determining such an allocation arises from the fact that these skills are interrelated. For example, the training required for proficiency in skill number 13, Medical Doctor, and in skill number 10, Electronic Engineer, is so diverse that it would be unreasonable to expect one man to possess both skills. On the other hand, a Medical Doctor could be expected to serve as a Microbiological Technician, skill number 12, with little, if any, additional training.

Provision is made for recognizing these constraints in the following manner. A set of "skill-mixes," groupings of skills which a single man may be reasonably expected to possess, are determined and coded as arrays of 20 elements as shown below.

SKILL CODE NUMBER	1	2	3	4	. . .	19	20
SKILL MIX ARRAY	(1,	1,	2,	2	. . .	0,	0)

The code number, 0, indicates that the man possessing this skill-mix can not perform tasks requiring the corresponding skill in the array; the code number, 1, indicates the ability to perform tasks with full proficiency; and the code number, 2, indicates the ability to perform tasks with a low level of proficiency. It is assumed that a crewman with a proficiency factor of 2 in a skill requires twice as much time to perform a given task as a crewman with a proficiency factor of 1 in that skill. These arrays represent the "types of men" from which the model may select. The collection may consist of 20 such arrays. In addition to the scientific skill specifications, 13 crew position specifications are built into the model logic.

Once a set of skill-mixes has been input, the skill optimization procedure will assign skill-mixes from this collection to the crewmen in such a manner as to obtain the best utilization of crew time during the launch period in question. These assignments are subject to the constraint that once a skill-mix is assigned to a man, the man must retain the skill-mix for the duration of the mission. The utilization is measured by the two indices given below:

Primary Index: $I_1 = E - W/C$

Secondary Index: $I_2 = 1000 \times (1 - \frac{W-E}{E})$

where

E = Total number of man-hours required to perform the experiments assigned during the launch period, assuming all tasks are accomplished with a proficiency factor of 1

W = Total number of man-hours actually utilized in performing the experiments

C = Maximum acceptable cost of a man-hour of experimental work in terms of man-hours of crew time (a model input).

The first index is based on the following method of comparing the utilization of two different crews. Let E_1, W_1 and E_2, W_2 represent the values of E and W for two different crews and assume that E_2 is greater than E_1. The cost of an additional hour of experimental work by the second crew in terms of additional man-hours of crew time is given by the expression $(W_2 - W_1)/(E_2 - E_1)$. The following policy is followed by choosing between the two crews:

$\frac{W_2 - W_1}{E_2 - E_1} > C$	First crew is selected
$\frac{W_2 - W_1}{E_2 - E_1} < C$	Second crew is selected
$\frac{W_2 - W_1}{E_2 - E_1} = C$	Crews are considered to be equally good.

The policy is mathematically equivalent to selecting the crew which gives the maximum value of the primary index, I_1. When the primary index is the same for two different crews, the crews are evaluated using the secondary index, I_2. This index is a measure of the efficiency of the crew in performing the experimental work and ranges in value from 1000 (all tasks performed with a proficiency factor of 1) to zero (all tasks performed with a proficiency factor of 2).

The logic of the optimization routine is shown in Figure 6-2. For each launch period, the crew is examined to determine which crewmen, if any, have been assigned skill-mixes previously. If there is only one man with no skill-mix assignment, this man is tentatively given each skill-mix, and the resulting crew is assigned work (by means of the PRM scheduling routine) from the experiments on board during the launch period. The skill-mix assignment that gives the best values of the two indices is retained.

When there is more than one man with no previous skill-mix assignments, a tentative crew is selected as follows: The crew is scanned to determine which of these men has the greatest number of available working hours; this crewman is given each skill-mix. Experiment tasks are assigned to this man and all other men with specified skill-mixes by means of a special assignment subroutine. (Experimental work is assigned on the basis of total available

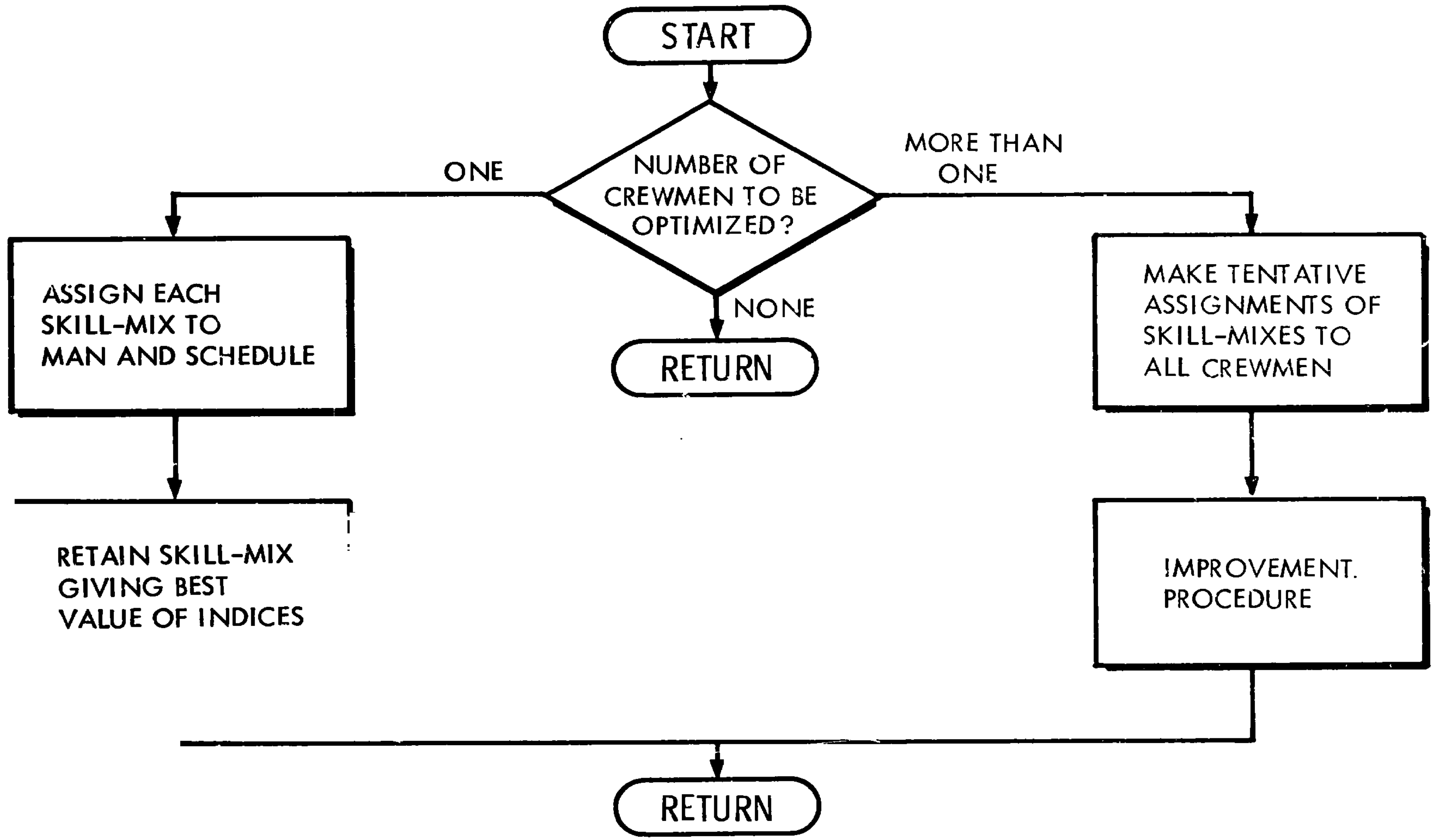


Figure 6-2 CREW SKILL OPTIMIZATION PROCEDURE

working hours during the launch period - time-lining is not considered.) As before, the skill-mix giving the best values of the two indices is retained. This process is repeated until all crew members have been assigned a skill mix.

Once a tentative crew has been selected, the assignments are reexamined to determine the crewman with the poorest utilization. When this crewman is identified, the model seeks to improve the crew utilization by exchanging the skill-mix of this man with that of each of the remaining men. The best of these exchanges is examined by use of the PRM scheduling subroutine. If an improvement is obtained, the improved skill-mix assignment is retained and the process is repeated; if not, each skill-mix is assigned to the man with the lowest utilization and the resulting crew is reexamined by use of the assignment subroutine. The best three of these crews are examined with the PRM scheduling subroutine. If one of these crews proves better than the current crew, it is retained and the entire process is repeated; if not, the entire process is repeated for the crewman with the next poorest utilization. This process is continued until an improvement is realized or until all crew members have been examined. The process is terminated automatically after a reasonable number of attempts at improvement have been made.

6.3.3 Development of Feasible Skill-Mix Types

In order to obtain realistic inputs for exercising the model, a preliminary set of skill-mixes compatible with the MORL baseline experiments was generated. The expected background and abilities of an astronaut in each of the 20 skills listed previously was hypothesized. An estimate was made of the proficiency at which an astronaut in a particular skill could be expected to perform (or trained to perform) the tasks associated with each of the remaining skills. It was assumed that "full proficiency" implied the ability to perform all tasks associated with the skill; that "low proficiency" implied the ability to perform these tasks with the aid of instruction manuals, advice, etc.; and that "no proficiency" implied the inability to perform these tasks.

This method was applied by a number of technical specialists at Langley Research Center and at the Fort Worth Division of General Dynamics. The set of skill-mixes that was developed from these data represents a moderately good agreement among the individuals involved. Although a more careful sampling technique would improve the consensus, these skill-mixes seem to be sufficient for the present stage of MORL mission definition. These mixes are itemized in Table 6-1. Each row of the table represents a set of estimated proficiency ratings in each of the 20 scientific skills required for the MORL program.

Table 6-1 CREW SKILL-MIXES FOR MORL EXPERIMENTAL PROGRAM

		Skill No. 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Biological Technician	1	1	1	2	2	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0
Microbiological Technician	2	1	1	2	2	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0
Biochemist	3	1	1	1	2	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0
Physiologist	4	1	1	2	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0
Astronomer/Astrophysicist	5	0	0	0	0	1	1	1	0	2	2	2	2	0	2	2	2	0	0	2	0
Physicist	6	0	0	0	0	1	1	1	0	2	0	2	2	0	2	2	2	2	0	2	0
Nuclear Physicist	7	0	0	0	0	2	1	1	2	2	2	2	2	0	2	2	0	2	0	0	0
Photo Tech/Cartographer	8	0	0	0	0	0	0	0	1	0	0	0	2	0	2	0	0	2	0	0	2
Thermodynamicist	9	0	0	0	0	0	2	2	0	1	2	2	2	0	0	0	2	0	0	0	0
Electronic Engineer	10	0	0	0	0	0	2	2	2	2	1	2	1	0	0	0	0	1	0	0	0
Mechanical Engineer	11	0	0	0	0	0	2	0	2	1	2	1	2	0	0	0	0	0	0	0	0
Electromechanical Tech.	12	0	0	0	0	0	2	0	2	0	2	2	1	0	0	0	0	0	0	0	0
Medical Doctor	13	1	1	1	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Optical Technician	14	0	0	0	0	0	0	0	2	0	0	0	2	0	1	2	0	0	0	0	0
Optical Scientist	15	0	0	0	0	2	2	0	2	0	0	0	0	0	1	1	0	0	0	0	2
Meteorologist	16	0	0	0	0	2	2	0	2	2	0	0	0	0	0	0	1	0	2	2	2
Microwave Specialist	17	0	0	0	0	0	2	0	0	0	2	0	2	0	0	0	0	1	0	0	0
Oceanographer	18	0	2	2	0	0	0	0	2	2	0	0	0	0	0	0	2	0	1	2	0
Physical Geologist	19	0	0	0	0	2	0	0	0	2	0	0	0	0	0	0	0	0	2	1	1
Photo Geologist	20	0	0	0	0	0	0	0	2	0	0	0	0	0	2	0	0	0	2	1	1

1 - Full Proficiency 2 - Partial Proficiency 0 - No Proficiency

6.4 Crew Illness Analysis

Crewmen may become ill during a mission and, as a consequence, man-hours will be lost, or, in more serious situations, the mission may be aborted. Degrees of illness and the appropriate action to be taken were considered in this analysis. The model structure to accommodate this action is discussed under Station Operations (Section 10.0). The rationale for this structure is presented in the following paragraphs.

Since the occurrence of a crew illness is probabilistic, the mechanics of its occurrence have been incorporated in the random event generation subroutine. To incorporate crew illness as a random event, it was necessary to assess the probability of an illness occurring as a function of time. The appropriate probability density function (pdf) was selected from this assessment and is input into the random event generation subroutine to simulate the occurrence of crew illness.

The necessary statistics to obtain the required mathematical relationships for the very specialized group involved are not available. Motivation, past history, and physical condition all play an important role in susceptibility to diseases. Astronauts are chosen from a very select group of men who make up the active pilot type personnel, so generalizations based on normal populations may be in error. It is recommended, therefore, that information about groups such as the Air Force personnel, which is already on tapes, be drawn upon for the specific purpose of model design. These data provide a very conservative estimate for model usage.

To facilitate the incorporation of crew illness events, crew illnesses have been divided into three mutually exclusive categories: major illness, minor illness, and contagious illness.

A major illness is defined as the occurrence of a noncontagious disease requiring immediate return to Earth and zero reliance upon the affected crew member. The kind of disease most likely to qualify as a major illness is an acute condition which does not respond to antibiotic therapy. A prevalent condition among pilots of this age group is peptic ulcer. In 1965, incidence among 868,461 Air Force personnel was 3290. Ulcers account for a large number of pilot hospitalizations and loss of time.

A minor illness is defined as the occurrence of a noncontagious disease which requires zero reliance upon the affected crew member for a nominal period of 48 hours. If it is assumed that slight illnesses normally accepted in a motivated crew member would also be endured in space, then an illness incident rate can be estimated. The Air Force expresses this as NER (Non-Effective Rate) or days lost for medical reasons. (This, of course, would include the patients suffering major illnesses. For exact studies, this number could be excluded with additional information on the subject.) This rate represents approximately 1 5 percent of all aircraft crew members. This is considered to be a reasonable figure for the program. It is assumed that the individuals will recover (otherwise, the matter would be of the C-type situation-abort). For program purposes, it is assumed that the patient will respond in 48 hours and that performance will be zero during that period. It is assumed that a longer illness would fall in the C category or necessitate return of the crewman.

A contagious illness is defined as the occurrence of an infectious disease requiring immediate station abort and zero reliance upon the affected crew member. It is assumed that cross-immunization was completed during crew training and that the isolation of the vehicle will decrease incidences of this type. It is possible, however, that the environment may decrease resistance to some organism carried by the crew members. In this case, the most susceptible individual would show symptoms first. This could justify immediate mission abort on the basis that other cases will follow. Infectious hepatitis is one illness prevalent in this age group and not likely to respond to onboard treatment. The prevalence of infectious hepatitis in the 30- to 40-year age group is considered high; thus, a reasonable probability for a complication by this type of disease is assumed to be 123/100,000. While the probability is quite small (0.1%), this condition could account for a very large time loss because it necessitates prolonged confinement.

It should be noted that extraction of these data without consideration of all factors involved may create minor errors. There are many statistics in addition to those presented above to draw from. Also, in some cases, information on submarine crews may be more appropriate than the Air Force experience. Consequently, the data presented should be considered as tentative data for use in model development.

Use of the random event generation subroutine requires that a probability distribution type be selected for modeling each of the random events such as crew illness. The likelihood of a crew member becoming ill was assumed to be constant during his stay at the space station. Consequently, the exponential distribution is appropriate for illness representation. The incident rate parameter for each type of illness was therefore determined for the exponential distribution representation. This parameter was then adjusted to reflect a crew size of six men.

The final rates, listed below by illness category, are representative of a six-man crew:

Illness Category	Illness Rate
Major	λ = 0.003785 events/year
Minor	λ = 16.44 events/year
Contagious	λ = 0.001230 events/year

6.5 Task Assignments

6.5.1 General

Tasks are initially assigned to each crewman in the Preliminary Requirements Model. These tasks are subject to limited reassignment and refined scheduling in the Space Station Model. As noted previously an effort is made to make assignments which are consistent with available resources and will result in a high crew utilization efficiency. The Space Station Model is also equipped to make contingency task assignments, thus providing greater flexibility of operation as well as reducing problem input requirements. The approach taken to contingency task assignments is discussed below.

6.5.2 Contingency Task Assignments

The purpose of the contingency task assignment procedure is to select the crew members for unassigned tasks, such as unscheduled maintenance, which arise during the probabilistic simulation of a mission. The philosophy followed in treating these events is that these tasks are to be scheduled immediately, even when this necessitates the interruption of previously scheduled activities. Contingency events of this type are predicated as a combination of as many as three one-man subtasks, each subtask requiring a specified number of hours of work to be performed by a crewman possessing a specified skill. An example of this type of task is a repair task which could require the work of a mechanical engineer for 2 hours and an electrical engineer for 1 hour.

Once the requirements of the task have been specified, the crewmen to be assigned to the task are selected on the basis of their proficiencies in the required skills, and these tasks are incorporated into the existing schedule of crew activities. In addition to skill considerations, it is clearly desirable to select the crewmen in such a manner as to produce a minimal disruption of the activities which have been previously scheduled.

An example of the procedure used in selecting the crewmen is shown in Figure 6-3. When the requirements of the contingency task have been specified, three different teams of crewmen, one man for each subtask, are selected. These men, who are designated as the principal workers on each subtask, are selected because of their ability to accomplish the job in the least amount of time. The selection is based on the total number of man-hours required by a team to perform the task; i.e., the sum of the times required of each man multiplied by the skill proficiency factor of the man. Once the principal workers are selected, an alternate man is selected, if possible, for each principal. The principal-alternate concept used here is the same as that used in the events scheduling

CONTINGENCY TASK ASSIGNMENT PROCEDURE

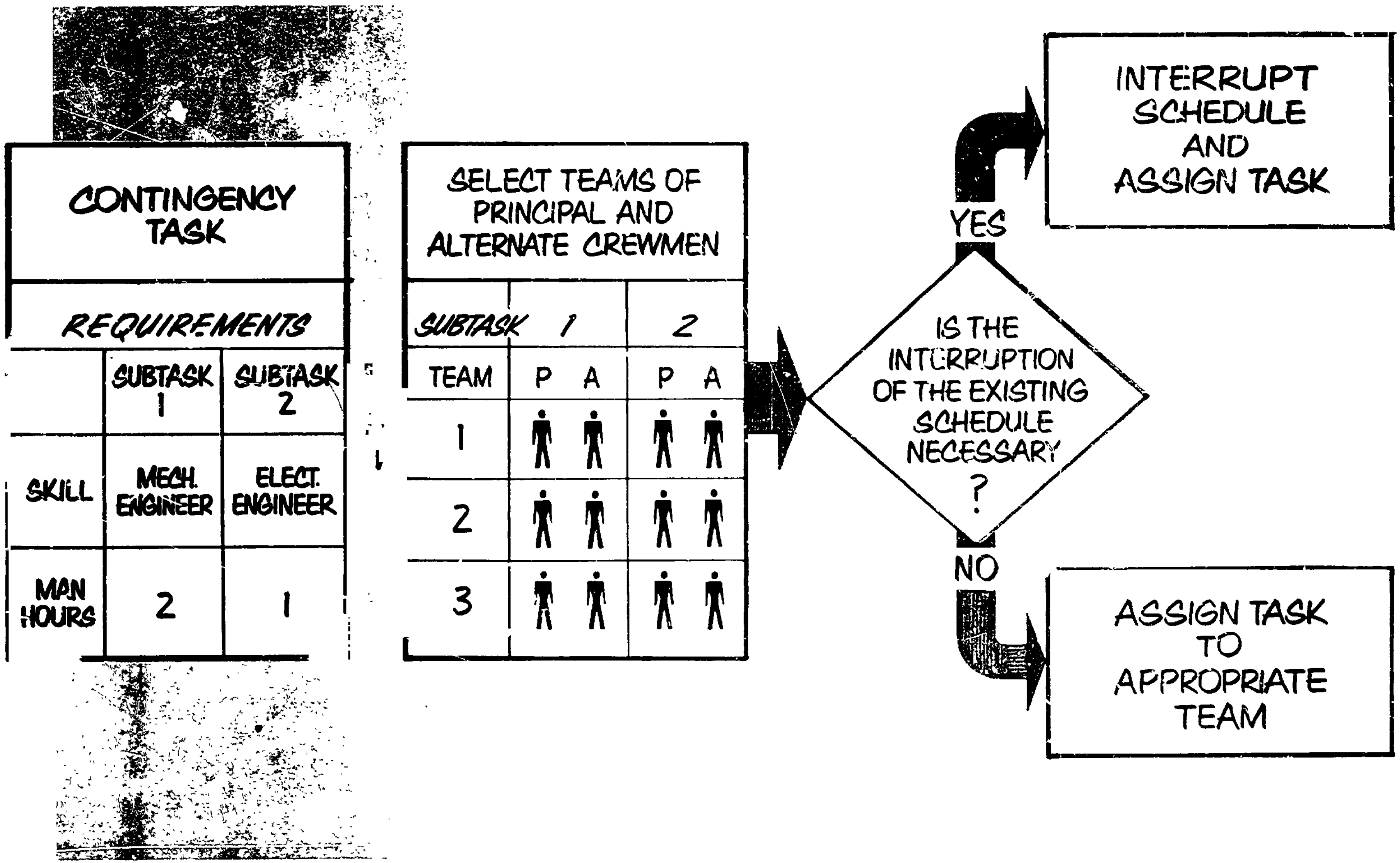


Figure 6-3

routine. Each day the work is assigned to the principal man if he is available; if not, the work is assigned to the alternate. This procedure yields three teams of crewmen, each team having a principal and al alternate worker for each subtask.

The teams are then examined to determine if the task can be assigned to any of the teams without interrupting the existing schedule of work. If so, the task is assigned to that team. If not, the existing schedule of work is interrupted as much as is necessary to schedule the task and the interrupted work is rescheduled at a later date.

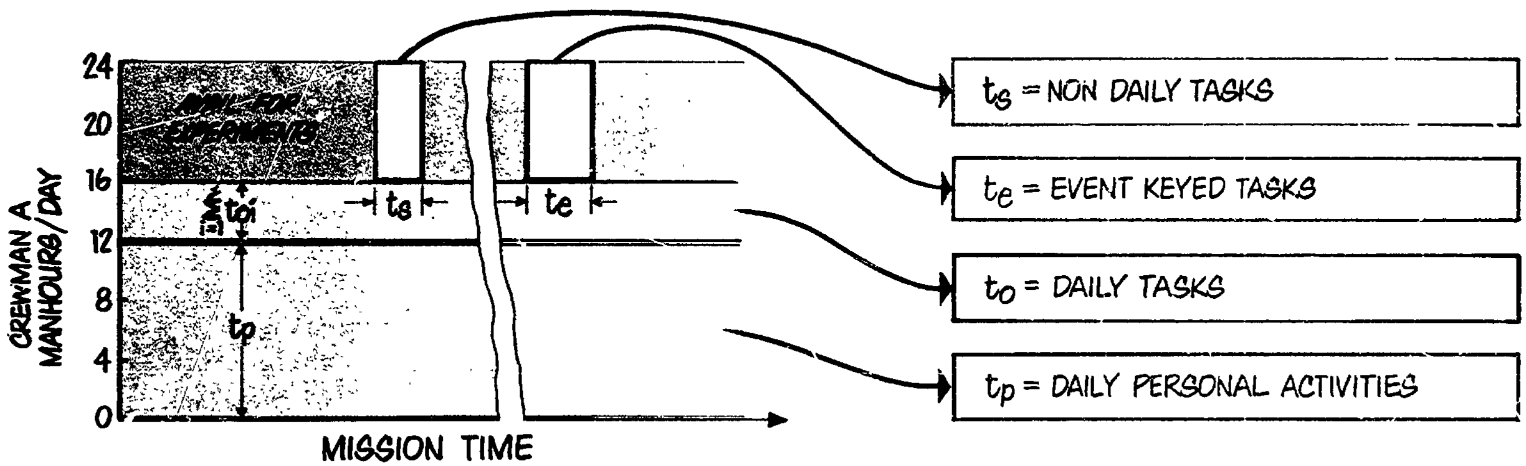
6.6 Task Libraries

In order to determine the man-hours/skill available for the experimental program, the crew's personal activities and station operational tasks are subtracted from the total man-hours/skill available (see Figure 6-4). This is accomplished in the model by collecting task descriptors and storing these data in the libraries for use by the assignment and scheduling logic. Since these data are subject to only infrequent changes, block library storage is utilized. This greatly simplifies the model's usage. Although computer storage limitations restrict the amount of data that can be stored, it was found that sufficient detail could be included to be consistent with the level of the rest of the model and the accuracy objectives.

STATION OPERATIONS CREW TASK LIBRARY

TYPICAL MANHOUR PROFILE

PRIMARY TASK CATEGORIES



$$MH_{AX} = 24 - \left(t_p + \sum_{i=1}^{i} t_{oi} + \sum_{k=1}^{l} t_{sk} + \sum_{m=1}^{n} t_{em}\right)_{T=X}$$

= EXPERIMENTAL MAN-HOURS ; CREWMAN A, MISSION DAY X

LIBRARY DATA TABULATION FORMAT

DAILY PERS. ACTIVITIES (t_p)		DAILY TASKS (t_o)			NON DAILY TASKS (t_s)					EVENT KEYED TASKS (t_e)			
ACTIVITY	TIME	TASK	TIME	CREWMAN SKILL	TASK	START DAY	TASK DURATION	INACTIVE PERIOD	CREWMAN SKILL	TASK	EVENT	TASK DURATION	CREWMAN SKILL
• SLEEP • EAT • PERSONAL HYGIENE • RECREATION													

Figure 6-4

Data for the crew task libraries were generated from an analysis of the task times and skills associated with the major categories shown below.

Personel Activities

- Sleep
- Recreation
- Eat
- Personal Hygiene

Operations

- Systems Monitoring
- Logistics Arrivals
- Cargo Transfers
- Logistics Vehicle Storage and Monitoring

Systems Maintenance

- Scheduled
- Unscheduled

For the Planning Mode these data were combined into the four groups illustrated above. The personal and daily tasks were summed and stored as one library entry. Separate entries are stored for each tasks in the other two task groups: (1) those that are non daily, but scheduable and (2) those that are keyed to mission events, such as logistics arrivals. These latter two groups are assigned to qualified crewmen and scheduled by the scheduling logic as the mission plan is developed.

These same data are used in the Simulation Mode where the contingency tasks associated with unscheduled events, such as system failures, are also included. If periods of temporary overloads are encountered, the personal activity times are allowed to decrease within the limits previously described before any task rescheduling is called for. The unscheduled maintenance repair time estimates, safe times, etc., are described elsewhere in this report.

The numerical values used for the tasks times and the skill requirements are included in a separate report. These data can be easily updated by altering the library data decks.

6.7 Crew Safety

An attempt was made to provide these real life elements in the model: (1) recognition of a situation which jeopardizes the safety of the crew and (2) cognizance of potential future threats.

The welfare of the crew may be threatened by many means; most of these may be categorized as accidents, illnesses, or failures in systems which provide vital functions. Illnesses or accidents which occur at the station may be accommodated in the model if the subsequent action taken is either (1) recuperation of crewman at the station while he receives no work assignments, (2) return of the crewman to Earth, or (3) abandonment of station. If an event or combination of events results in a call for station abort, the outcome of the abort can be determined by simulation. Thus it is determined if the crew is successfully returned.

In addition to these actions which take place after crew safety has been compromised, the efficiency subroutine discussed in the station operations section periodically examines the probability of crew survival, with and without a special logistics launch, out to the end of the scheduled supply interval. In this way, special logistics launches can be used to improve crew safety when a potential threat looms.

Although the examples cited are the more obvious means of reflecting a policy of high crew safety, other means exist in the basic philosophy of model structure and operations. For example, it is the general policy to attempt repairs after failure in a critical system as soon as possible. An alternative approach might be to defer repair in preference to experimental work in progress until a more advantageous time, provided, of course, it is still within the critical repair time period.

The model is structured to consider the welfare of the crew for most conceivable circumstances. However, present data describing the likelihood of events such as accidents occurring in the station, in transient to the station, or during EVA are presently inadequate to obtain a full appreciation of their significance. Useful information can be obtained in cases such as these through the use of sensitivity analyses, wherein parameter values are systematically varied and the subsequent results analyzed.

7.0 EXPERIMENT ANALYSIS

7.1 Introduction

The Preliminary Requirements Model, utilizing a simplified scheduling routine, requires that only the experiment duration, total man-hours, and skill requirements be known. However, for the more detailed analyses performed in the Planning Mode and Simulation Mode, this abbreviated list of descriptors is inadequate. The purpose of the experiment analysis was (1) to determine which characteristics (descriptors) should be used to describe the experiments in these modes, and (2) to obtain and code for model input a set of experiments representative of the scientific activity during a typical mission. The baseline set of scientific experiments proposed for the Manned Orbital Research Laboratory was reviewed and analyzed for this purpose. The overall analytical process is illustrated in Figure 7-1.

7.2 Experiment Descriptors

The analysis of the baseline experiments indicated that a total of 32 descriptors would be sufficient to provide an accurate characterization of a broad spectrum of experimental activity. The magnitude of the parameters associated with each of these descriptors was determined, when applicable, for each of the baseline experiments. A list of these descriptors is given below:

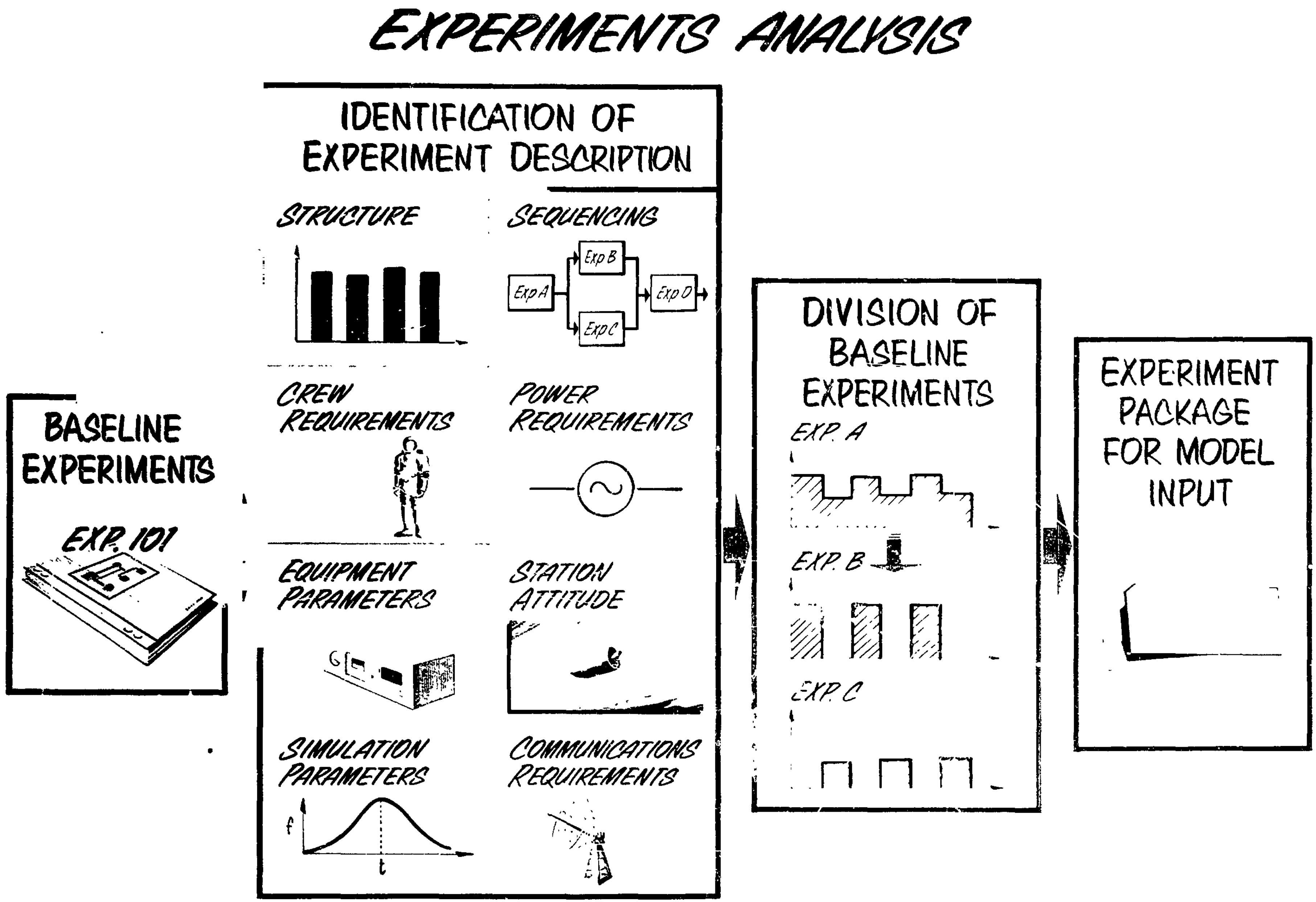

EXPERIMENTS ANALYSIS
BASELINE EXPERIMENTS
EXP. 101
IDENTIFICATION OF EXPERIMENT DESCRIPTION
STRUCTURE
SEQUENCING
Exp A
Exp B
Exp C
Exp D
CREW REQUIREMENTS
POWER REQUIREMENTS
EQUIPMENT PARAMETERS
STATION ATTITUDE
SIMULATION PARAMETERS
f
t
COMMUNICATIONS REQUIREMENTS
DIVISION OF BASELINE EXPERIMENTS
EXP. A
EXP. B
EXP. C
EXPERIMENT PACKAGE FOR MODEL INPUT

Figure 7-1

1. Structure Descriptors - These descriptors are used to specify the structure of the resource requirements and the schedule of activities of an experiment with respect to time.

   (a) Duration - The number of days required to complete the experiment. A special provision is made for experiments that, once initiated, are expected to continue for the duration of the mission. These descriptors are assigned a value of -1, which causes the duration of the experiment to be extended automatically to the end of the mission.

   (b) Number of Active Periods - This descriptor is used to specify the number of times a set of activities is to be repeated during the experiment.

   (c) Active Period Length - A repetitive experiment may require crew time for a certain number of days during a cycle and require none during the remainder of the cycle. This descriptor indicates the number of days crew time is required.

   (d) Inactive Period Length - This descriptor specifies the number of days that no crew time is required.

   (e) Start Day Active - This descriptor specifies whether or not the start day of the experiment is active.

An example of the relations between these descriptors is given in Figure 7-2.

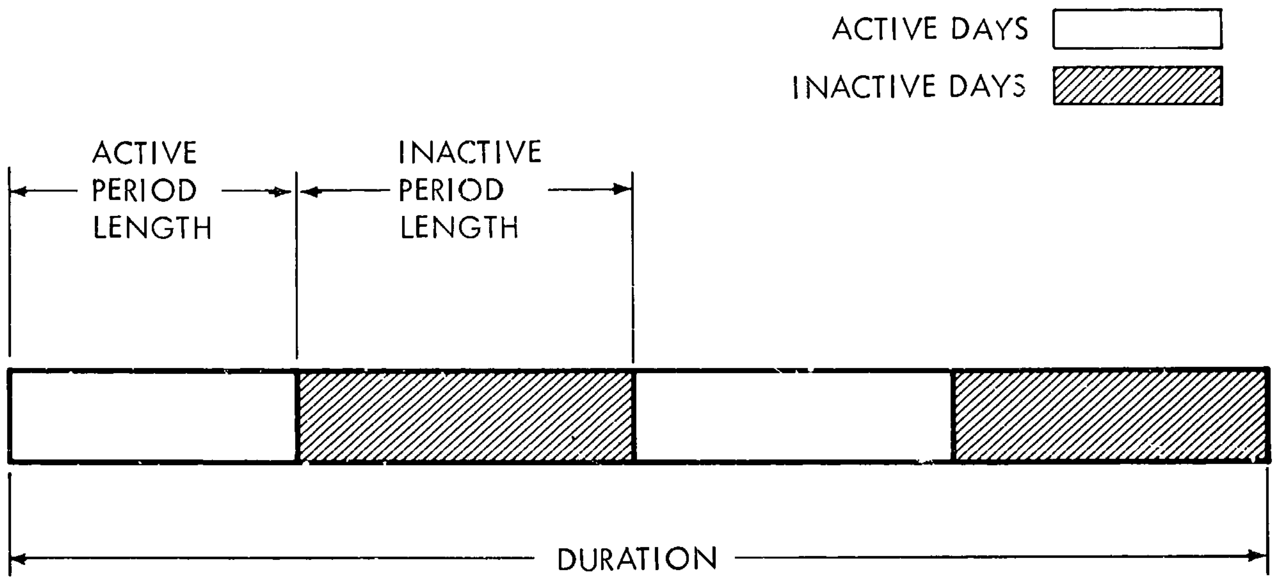


Figure 7-2 AN EXAMPLE OF EXPERIMENT STRUCTURE

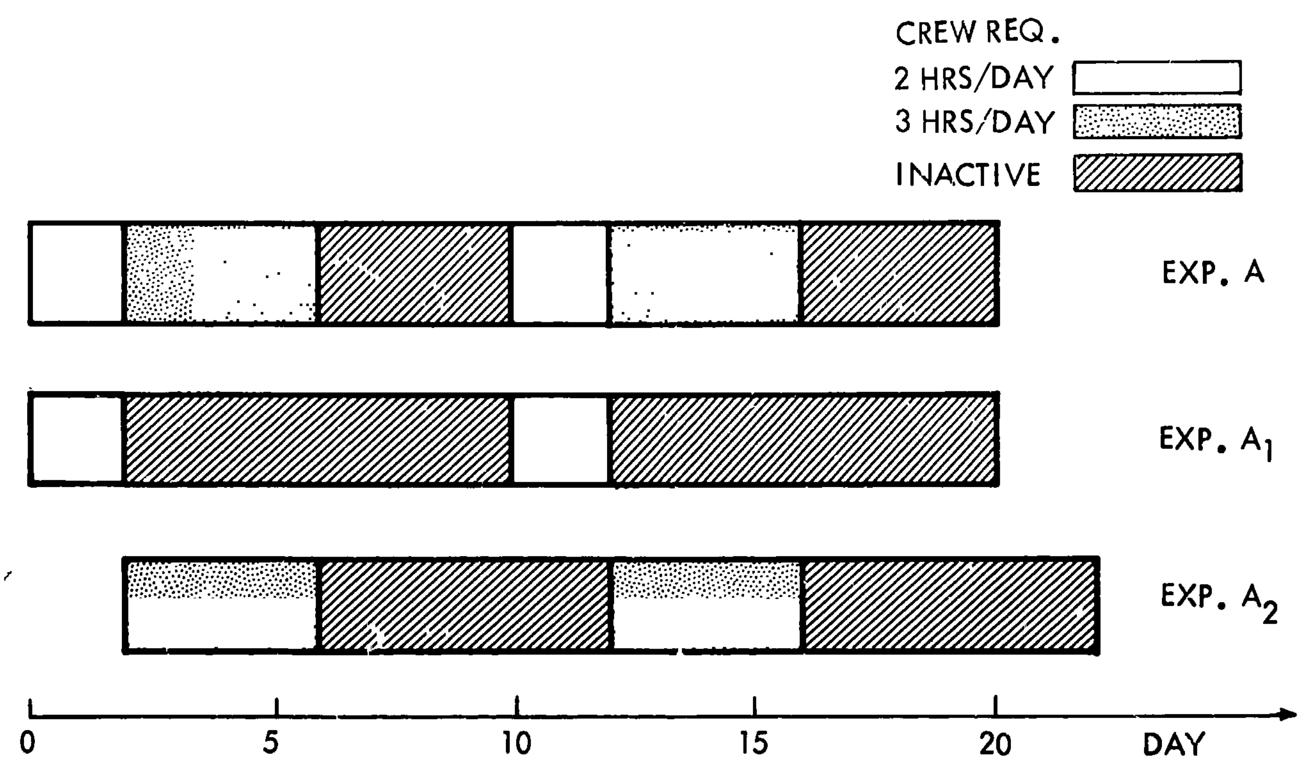


Figure 7-3 THE BREAKDOWN OF AN EXPERIMENT INTO TWO SEQUENCED EXPERIMENTS WITH SIMPLE PERIODIC STRUCTURES

2. Sequencing Descriptors - These descriptors can be used, as desired, to control the sequencing of the experiments in time.

(a) Force Start Date - This descriptor is used to specify a particular mission day for initiating the experiment.

(b) Successor Experiment Number - This descriptor designates another experiment which is to follow in sequence.

(c) Successor Experiment Delay Time - The number of days between the start date of one experiment and the start date of its successor. If this descriptor is given a value of zero, both experiments will start simultaneously.

(d) Predecessor Experiment Number - This descriptor designates an experiment which is to precede the experiment.

3. Crew Requirements Descriptors

(a) Number of Men Required - This descriptor indicates the number of men required to perform the experiment. No more than three men may be designated to perform a single experiment.

(b) Skill Type - There are three such descriptors associated with each experiment. Each descriptor specifies the skill type of one of the men.

(c) Hours per Day - There are three such descriptors associated with each experiment. Each descriptor gives the number of hours per active day that one man is to work on the experiment.

4. Power Requirements Descriptors

(a) Peak Power, AC and DC - These descriptors reflect the peak power in watts required by the experiment on an active day.

(b) Duration of Peak, AC and DC - These descriptors reflect the number of hours of peak power required during an active day.

(c) Continuous Power, AC and DC - These descriptors indicate the power in watts required by the experiment in a 24-hour day.

5. Equipment Descriptor

(a) Weight - Equipment weight is expressed in pounds.

(b) Volume - Equipment volume is expressed in cubic feet.

(c) Special Equipment - This descriptor indicates a requirement for a major or special equipment such as a special experiment module.

6. Communication Requirement Descriptors

(a) Voice Hours - This descriptor is used to specify the number of voice hours per active day required by the experiment.

(b) TV Hours - This descriptor is used to specify the number of television hours per active day required by the experiment.

(c) Digital Data - This descriptor reflects the number of digital bits (times 10^6) transmitted per active day.

7. Station Attitude Requirement Descriptor

(a) Attitude - This descriptor indicates the space station attitude requirement, if applicable, for the performance of the experiment. The two types of attitude requirements which are recognized are inertial and belly-down.

8. Simulation Descriptors (These descriptors are used to indicate the properties of the experiments which may vary during a probabilistic simulation)

(a) Optimistic and Pessimistic Number of Active Periods - These two descriptors are used when there is uncertainty in the number of cycles required by an experiment. Both optimistic and pessimistic estimates are input. The model selects a number from a distribution based on these values.

(b) Interruptible - Interruption of a current experiment may be necessary when unscheduled events arise during a simulation. This descriptor specifies whether or not an interruption of the experiment will provide a degradation of the data.

7.3 Division of Baseline Experiments

The majority of the experiments in the baseline set can be fully characterized by the descriptors discussed; however, a number of these experiments cannot be coded for model input as a single experiment. Generally, these experiments either require more than three men for their performance or require a schedule for activities more complicated than a single repetitive structure.

Although such experiments cannot be coded as single experiments, the successor-predecessor mechanism permits these experiments to be coded as two or more experiments. An experiment with a very complex schedule of tasks and requirements may be treated by a process consisting of (1) the analysis of the experiment into a number of tasks exhibiting a repetitive structure; (2) the coding of each of the tasks as separate experiments; (3) the tying together of the tasks by use of the successor-predecessor mechanism. This process is illustrated in Figure 7-3. Applying this technique to the baseline experiment, it was found that all of the experiments could be translated into a form suitable for model input. An example follows:

The designation of Experiment B as the successor of Experiment A with a delay time of n days will cause the model to treat both experiments as a single unit. Whenever the model attempts to schedule Experiment A, it will also attempt to schedule Experiment B, starting this experiment n days later. If the resource levels are such that the requirements of one of these experiments cannot be satisfied, neither will be scheduled. Also, the designation of Experiment C as a successor to Experiment B will provide a chain of three experiments which will be treated as a single unit

8.0 LOGISTICS ANALYSIS

8.1 Introduction

The logistics routine is used to incorporate the effects of a specified logistics system into the model station operations and, subsequently, to evaluate the impact of logistics systems upon the cost and effectiveness parameters of these operations. This objective is accomplished by use of a logistics routine which simulates the critical operations associated with logistics support. In simulating these operations, the logistics routine accepts dynamic launch requests from the space station and, then, subject to the capability constraints of the system, acts to satisfy these requests. An assessment of the logistics system's ability to satisfy the station's request and the cost of the logistics system are then weighed to determine the system's effectiveness in support of the space station.

Logistic support is required for three space station operations: launching of the space station, manning of the space station, and fulfilling support requests from the space station. After the station is established in its orbit, the requests for logistics support can be divided into two categories: (1) scheduled requests and (2) unscheduled requests. The scheduled requests are those that are generated from nominal station operations and, hence, can be scheduled into the program plan several days before they are to be satisfied. The unscheduled requests are those that are generated by space station contingencies and, hence, can not be scheduled into the program plan until the contingency occurs. All requests, both scheduled and unscheduled, are categorized as one of the following: (1) crew requests, (2) fixed equipment requests, (3) experimental equipment requests, and (4) expendables requests.

The logistics routine was developed to simulate the operations of a logistics system consisting of a launch vehicle, a multimission cargo module, and a crew carrier with its associated service pack. The support system consists of a launch complex with N launch pads and a down-range recovery system with M deployable recovery forces.

8.2 Logistics Routine Responsibilities

The responsibilities of the logistics routine are to satisfy all space station support requests, subject to the logistics system's capability constraints. In order to allow for dynamic requests and to provide the capability of evaluating the resulting interaction created by these requests, this routine simulates the outcomes of all logistics and support system operations. As illustrated in Figure 8-1, the routine accepts space station support

LOGISTICS ROUTINE

ACCEPTS

- SPACE STATION SUPPORT REQUEST GENERATED FROM:
  - CREW ROTATIONAL PROFILES
  - SCHEDULED RESUPPLY PROFILES
  - UNSCHEDULED REQUESTS

ROUTINE FUNCTION

- SCHEDULES LAUNCHES, *Subject to constraints on*:
  - LAUNCH RATES
  - DAYLIGHT LAUNCH WINDOWS
  - DEAD ZONES
  - RECOVERY FORCES
- PACKAGE PAYLOADS, *Subject to capacity constraints on*:
  - LOGISTICS CARRIER
  - STATION CAPACITY
- SIMULATES LOGISTICS OPERATIONS
  - LAUNCH FACILITY COMPLEX
  - LAUNCH COUNTDOWN
  - VEHICLE LAUNCH TO RENDEZVOUS OPERATIONS
  - RECOVERY FORCE DEPLOYMENT

Figure 8-1

requests and the schedules launches, packages payloads, (subject to system constraints), and simulates the outcomes of the logistics operations. The space station support requests are generated from crew rotation profiles, scheduled resupply requirements, and unscheduled requests arising from station contingencies.

In scheduling the launches to satisfy these requests, the following factors are considered: (1) launch rates, (2) lighting conditions at the time of the launch windows, (3) deployment of recovery forces, and (4) interference with other space programs requiring the use of launch and tracking facilities. The launch rate is treated as a constraint. The model user has the option of using the other factors as constraints if desired.

The payload packaging of each logistics carrier is constrained by both the capacity of the logistics carrier and the station's storage capacity. The constraints on the carrier capacity are contained within the logistics routine itself. The constraints on the station capacity for expendables are considered in the expendables calculation routine, discussed in Section 10. There are no constraints on the station's capacity to store fixed and experimental equipment; this cargo can be stored, as required, in the multimission modules attached to the station.

Additional factors which are considered in evaluating a logistics system are the launch facility complex, the deployment of recovery forces, and the actual launch - from countdown to final rendezvous and docking maneuvers.

8.3 Basic Concept

The concept adopted in the logistics analysis was to develop a single routine which could be used by the Preliminary Requirements Model (PRM) and by the Space Station Model in both the Planning and Simulation Modes.

By the proper selection of routine options and data inputs, this single logistics subroutine can be used in the three different control programs. In the PRM and the Planning Mode of the SSM, no probabilistic events are considered. This restricts the routine in these two modes of operation to payload packaging and launch scheduling. The consideration of probabilistic events is eliminated in these models by setting all probability values within the logistics routine to 0 or 1.

The basic input, logic flow, and output of the logistics routine are illustrated in Figure 8-2. The input data for the logistics routine come from three different sources: problem input data, other routines, and library data. Selection of the data source depends upon the control program being used. The PRM requires the most problem input data and the Simulation Mode requires the least. The division of input data for each model can be obtained from scanning the model input requirements documented in the program material. In all cases, data describing the logistics system performance parameters are contained in the logistics routine library.

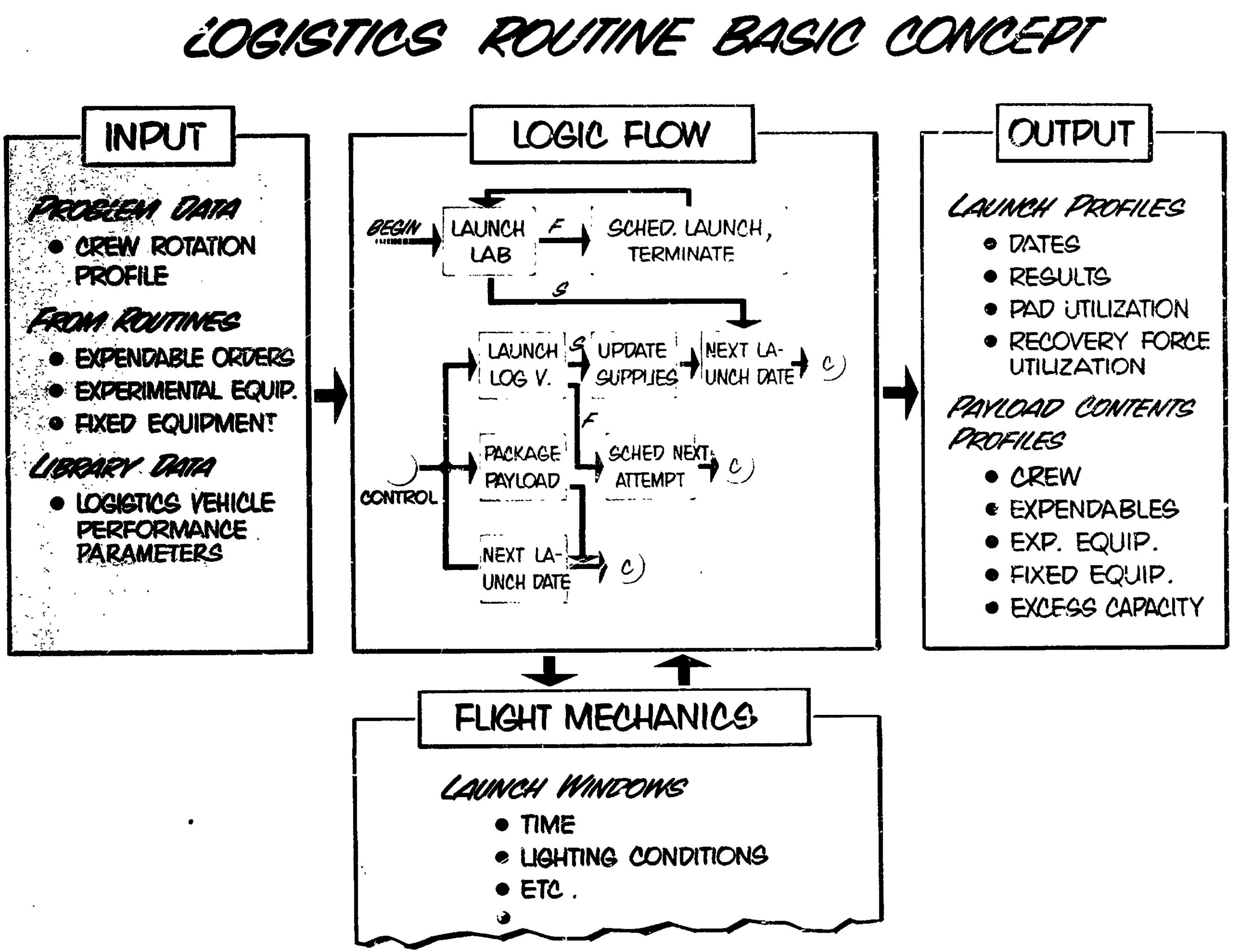

LOGISTICS ROUTINE BASIC CONCEPT
INPUT
PROBLEM DATA
• CREW ROTATION PROFILE
FROM ROUTINES
• EXPENDABLE ORDERS
• EXPERIMENTAL EQUIP.
• FIXED EQUIPMENT
LIBRARY DATA
• LOGISTICS VEHICLE PERFORMANCE PARAMETERS
LOGIC FLOW
BEGIN
LAUNCH LAB
F
SCHED. LAUNCH, TERMINATE
S
LAUNCH LOG V.
S
UPDATE SUPPLIES
NEXT LAUNCH DATE
C
F
PACKAGE PAYLOAD
SCHED NEXT ATTEMPT
C
CONTROL
NEXT LAUNCH DATE
C
OUTPUT
LAUNCH PROFILES
• DATES
• RESULTS
• PAD UTILIZATION
• RECOVERY FORCE UTILIZATION
PAYLOAD CONTENTS PROFILES
• CREW
• EXPENDABLES
• EXP. EQUIP.
• FIXED EQUIP.
• EXCESS CAPACITY
FLIGHT MECHANICS
LAUNCH WINDOWS
• TIME
• LIGHTING CONDITIONS
• ETC.

Figure 8-2

The primary outputs of the logistics routine are the program launch profile and the description of the payload contents of each launch (see Figure 8-2). The description of the program launch profile includes such factors as launch dates, simulated success or failure results of each launch, launch pad and recovery force utilization, and the active logistics scheduling constraints. The description of the payload contents is divided into the numb.r of crew delivered and the weight and volume allocated to expendables, fixed equipment, experimental equipment, and excess capacity.

8.4 Routine Interface

One of the early tasks in the development of the logistics routine was to identify the points of interface between this routine and the remainder of the Space Station Model (see Figure 8-3). It was then possible to develop the Space Station Model and the logistics routine in a modular form. This allows the Space Station Model to utilize the logistics routine (as well as all other routines) as computational subroutines. The logistics routine itself has been constructed as a set of interrelated subroutines, as shown in Figure 8-3. With each of the subroutines performing a specific portion of the logistics simulation. The operation of this modular procedure is described in the following paragraphs.

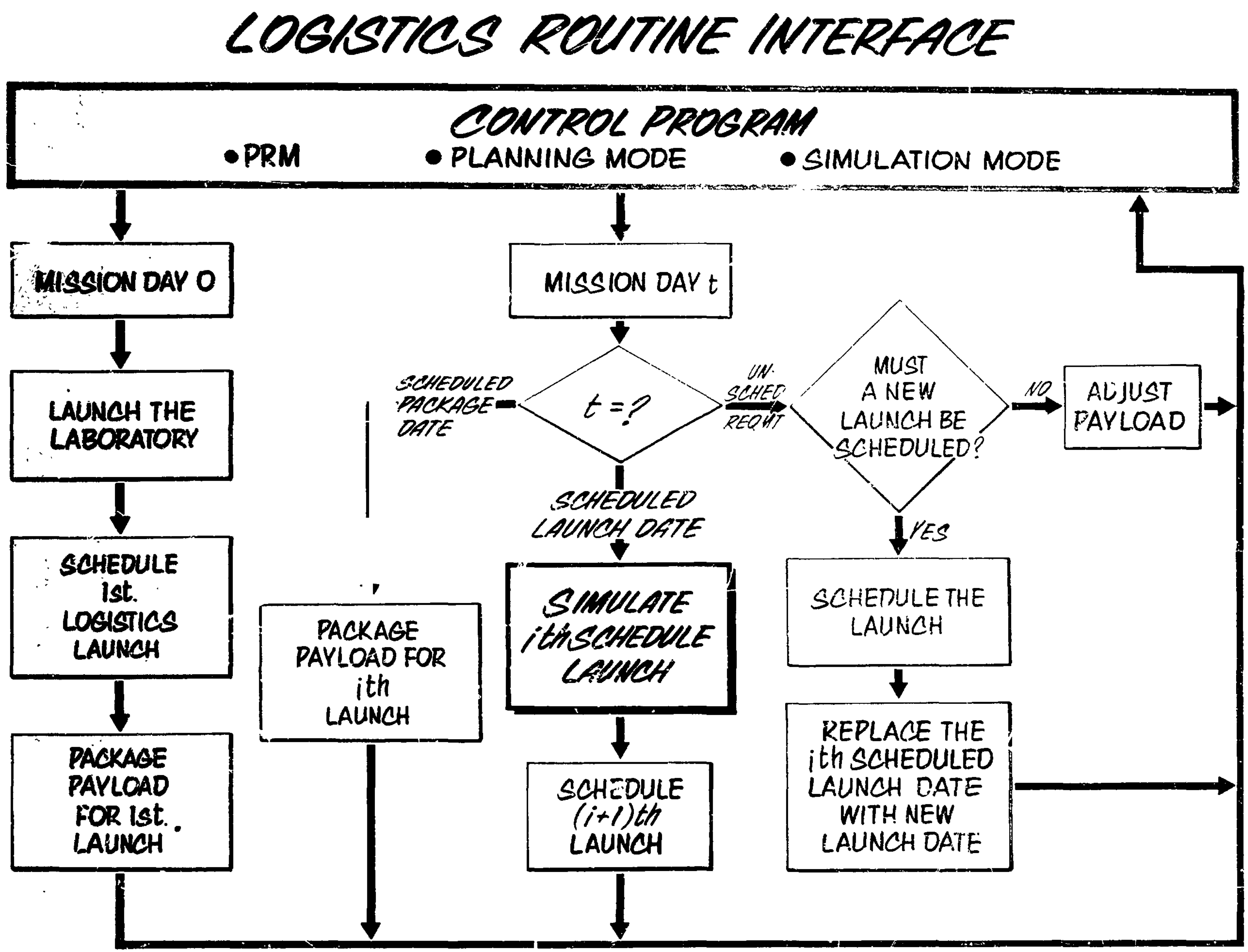

LOGISTICS ROUTINE INTERFACE
CONTROL PROGRAM
• PRM
• PLANNING MODE
• SIMULATION MODE
MISSION DAY 0
LAUNCH THE LABORATORY
SCHEDULE 1st. LOGISTICS LAUNCH
PACKAGE PAYLOAD FOR 1st. LAUNCH
PACKAGE PAYLOAD FOR ith LAUNCH
MISSION DAY t
SCHEDULED PACKAGE DATE
t = ?
UN-SCHED REQ'T
SCHEDULED LAUNCH DATE
SIMULATE ith SCHEDULE LAUNCH
SCHEDULE (i+1)th LAUNCH
MUST A NEW LAUNCH BE SCHEDULED?
NO
ADJUST PAYLOAD
YES
SCHEDULE THE LAUNCH
REPLACE THE ith SCHEDULED LAUNCH DATE WITH NEW LAUNCH DATE

Figure 8-3

When the Space Station Model requires information involving logistics operations, it identifies the present status of the space station and calls the logistics routine. Then, the appropriate set of subroutines within the logistics routine is called in sequence to generate the required information. Once the logistics information is generated, a return to the Space Station Model proper is executed.

The first call for the logistics routine effects launch of the space station itself, scheduling of the first logistics launch, and payload packaging for that launch. The next call for the logistics routine is to simulate the first logistics launch and to schedule the next launch. After this entry, the logistics routine may be called upon at any time to perform one of the following functions: (1) package the payload for the i^{th} logistics launch, (2) simulate the i^{th} logistics launch and schedule the $(i + 1)^{th}$ launch, (3) satisfy an unscheduled logistics requirement or (4) determine the earliest date for which a launch may be scheduled. The unscheduled logistics requirement can be satisfied by altering the payload of a scheduled launch or by changing the existing launch schedule as shown in Figure 8-3, e.g., sliding an existing launch date forward or adding an additional launch.

8.5 Description of Logistics Subroutines

The logistics routine is comprised of an integrated set of subroutines, each designed to perform a specific function. The objectives and concepts of these subroutines are described on the following pages.

8.5.1 Launching the Laboratory

The first subroutine within the logistics routine simulates the launching of the laboratory. This subroutine is entered with a specific calendar day, i.e., the desired space station program start date. Launch scheduling constraints are examined and the subroutine determines the first calendar day on or after the entry date, on which a laboratory launch can be made. The subroutine is then advanced forward in time to this launch date. At this time the launch of the laboratory is simulated. If the launch is successful, the logistics routine advances to scheduling of the first logistics launch. (The time required for unmanned checkout of the laboratory is a constant or variable depending upon the program option selected.) If the launch is not successful, a new laboratory launch is scheduled and simulated. This process is continued until a successful launch is accomplished or the supply of laboratories is depleted.

8.5.2 Scheduling Logistics Launches

The function of the logistics scheduling subroutine is to accept the space station support request and, subject to the launch scheduling and logistics carrier capacity constraints, schedule launches that will satisfy these requests. The scheduling is accomplished in a two phase effort. Phase one is the determination of desired launch dates. In phase two these dates are checked for compatibility with the scheduling constraints. Desired launch dates are determined by entering the scheduling subroutine on any mission day and determining the mission day of the next support request for each of the logistics categories. The date of the next support request for any category may be the subroutine entry date if all previous supply requests have not been satisfied or if a station contingency has occurred and unscheduled supplies are being ordered. The earliest of the four category request dates is the next desired launch date. If the desired launch date is compatible with the launch scheduling constraints, it becomes the next scheduled launch date. If this date is not compatible, the first compatible date after the request date is selected and this date becomes the scheduled launch date. Once the launch date has been scheduled, a return to the control program is executed.

The logistics subroutine receives the support request in the form of four matrices expressing the desired supply dates, amounts requested (weight and volume), and the multimission module types needed for each of the four logistics categories. In the PRM and the Planning Mode, a special logistics control subroutine is used to drive the scheduling and packaging subroutines through the entire mission duration. This eliminates any dynamic interactions with the other subroutines and results in a "planned" logistics profile for the entire mission. This profile is used for program planning by the other model routines.

In the Simulation Mode, it is necessary for the logistics scheduling subroutine to be dynamically responsive to the changing requests of other subroutines. The logistics scheduling subroutine becomes dynamic in the Simulation Mode by (1) letting any subroutine change the number and/or dates and the amounts requested for each of the supply request matrices and (2) scheduling only the current launch requirements. If a change in one of the request matrices is made, the logistics scheduling subroutine is notified to determine if a change in the existing launch schedule is required. If so, the change in the launch schedule is made before returning to the control program. Thus, if a contingency occurs in the space station, an additional launch may be scheduled, an existing launch date may be changed, or a payload package may be changed, depending upon the requirements of the contingency.

8.5.2.1 Launch Vehicle Availability - Given a desired launch date, the first constraint to be considered is the availability of a launch vehicle and its support requirements. The launch vehicle availability subroutine is used to determine the first mission day on or after the input date that a launch vehicle can be available. The procedure used in this routine is that K launch pads and L vehicles are given a program start status. When the mission is started, the ground support system is activated. The cycle of operations considered for each launch pad is launch, turnaround, and hold. The turnaround operations include the refurbishment of the launch pad and the delivery of a new launch vehicle, i.e., a vehicle which has progressed to a hold status of t-3 days. Launch vehicles are held at this position until they are needed; thus, the minimum notice for launching an unscheduled vehicle is 3 days. The pad use cycle is a rotation through the K pads available, with the laboratory launch always using pad number 1.

8.5.2.2 Launch Window Availability - The launch window availability subroutine is used to determine (1) the first mission day on or after the input date that a daylight launch window is available and (2) the midpoint (in hours) of that launch window. The launch window availability subroutine is a cycling routine for the flight mechanics subroutine, discussed in Subsection 8.5.6.

8.5.2.3 Dead Zone Interference - Dead zones are fixed intervals of time in which no launches are made. These zones can be used to allow for interface with other space programs requiring the use of launch facilities. The dead zone interference subroutine is used to determine the first day on or after the input date on which there is no launch interference with other space programs. If the input date falls within the free interval, it is taken to be the next available launch date; however, if the input date falls within the restricted interval, the next available launch date is the first day beyond the restricted interval. The calculations of this subroutine are based upon four parameters (1) a cycle duration, (2) the number of free days within this cycle, (3) the number of restricted days within this cycle, and (4) the day within the cycle that the space station program starts (see Figure 8-4).

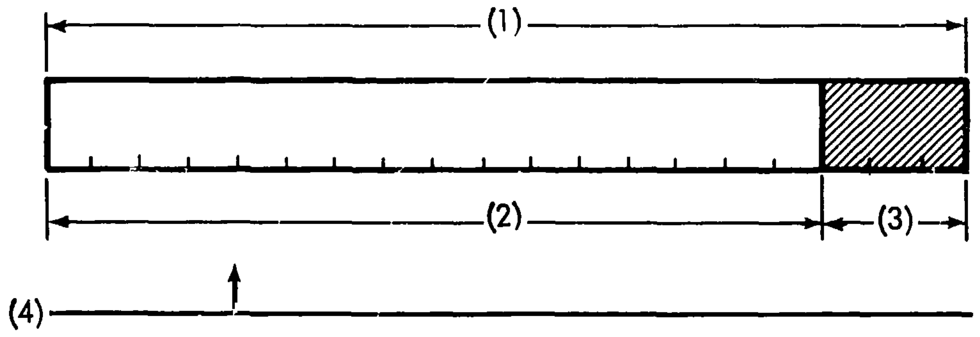


Figure 8-4 DEAD ZONE CYCLE

8.5.2.4 Recovery Force Availability - The recovery force availability subroutine is used to determine the first day on or after the input date for which a recovery force can be on station. The procedure used in this subroutine is similar to that of the launch vehicle availability subroutine. The K recovery forces are given a program start status. When the mission is started, the recovery force system is activated. The cycle of operations for each recovery force is deployment, time on station, and recycle to the holding position. Once a recovery force is placed on station, i.e., ready for a logistics launch, it is treated as if it will remain there for it's entire allowable time on station. Upon leaving the recovery area a force is recycled and held in the staging area until it is called for. In selecting the recovery force for deployment, the objective is to pick the force which will cause no launch delay or the minimum delay, whichever is applicable. If more than one recovery force meets the delay criterion, a priority selection is made.

8.5.2.5 Launch Scheduling Options - The launch scheduling factors presented above are used as launch scheduling constraints or as pseudo constraints depending upon the scheduling option selected by the model user. There are two launch scheduling options.

If the unconstrained launch scheduling option is selected, there is no time limit for scheduling a requested launch and the launch is scheduled for the first compatible day on or after the desired launch date. If the constrained launch scheduling option is selected, the launch must be scheduled within a given launch tolerance interval. This interval begins with the desired launch date and ends with the desired launch date plus delta days, where the delta is an input parameter. In this option, the pseudo constraints of the scheduling subroutine may be violated as required to obtain a launch date within this interval; however, the launch date selected will require a minimum number of violations of the pseudo constraints.

The pseudo constraints in the launch scheduling operations are (1) daylight launch windows, (2) dead zone interference, and (3) the deployment of recovery forces. No scheduling option is allowed to violate the launch vehicle availability constraint; thus, it is possible that a launch may not be scheduled within the launch tolerance interval when the constrained scheduling option is used.

Another launch scheduling option may be created by selecting the unconstrained scheduling option and relaxing the daylight launch window constraint.

The scheduling options will be overridden when an unscheduled logistics requirement must be satisfied by an alteration in the scheduled launch profile. In this case the unscheduled requirement is always satisfied on or as soon after the request date as possible, without any input directives.

8.5.3 Packaging Payloads

The function of the packaging payload subroutine is to determine the payload composition for each logistics launch. This is accomplished in a three-phase effort. In phase one, the four request matrices for expendables, fixed equipment, experimental equipment, and crew requirements are "lined up". That is, staggered requests are slid into alignment in time, within specified limits and, where required, launches which do not have request in all four categories are allowed. The type of multimission module to be used for each launch is determined in phase two. This is done on a priority rating basis. Each support request, by category, has a multimission module-type associated with it. The module type for each launch is taken to be the highest priority among the request categories.

The actual payload packaging is performed in phase three. In this phase, the support requests of each launch are subjected to the logistics carrier capacity constraints. If all requests at the time of the launch can be satisfied, the logistics carrier is loaded with those requests, and any excess capacity is noted. If all requests at the time of the launch can not be satisfied, the logistics carrier is loaded to capacity and the supplies which could not be loaded are placed on standby status. These supplies are then sent on the first payload that has any excess capacity for these types of supplies. When all requests for any launch can not be satisfied, priorities are used to establish the payload:

1. Expendables requirements

2. Fixed equipment requirements

3. Experimental equipment requirements

In priority packaging all requests within a category are satisfied before a lower priority category is considered.

8.5.4 Simulation of Logistics Launches (Simulation Mode Only)

This subroutine for simulating logistics launches is illustrated in Figure 8-5. The sequence of operation in this subroutine is the simulation of the countdown, launch, and rendezvous and docking operations. If the entire process is successful, the launch results and the payload contents are documented as printout. If a failure occurs during any of the operations, the launch vehicle inventory is checked to determine if another vehicle is available. If no vehicle is available, the station scheduling subroutine is notified. If another launch vehicle is available, the logistics launch scheduling subroutine is used to determine the next possible launch date. When this date has been determined a return to the control program is executed. When the control program has advanced in time to this new launch date, the logistics launch subroutine will be called again and this process is repeated until a successful launch is made or an abort is called. (The abort may be called because of lack of vehicles or failure to meet a critical time requirement.)

SIMULATION OF LOGISTICS LAUNCHES

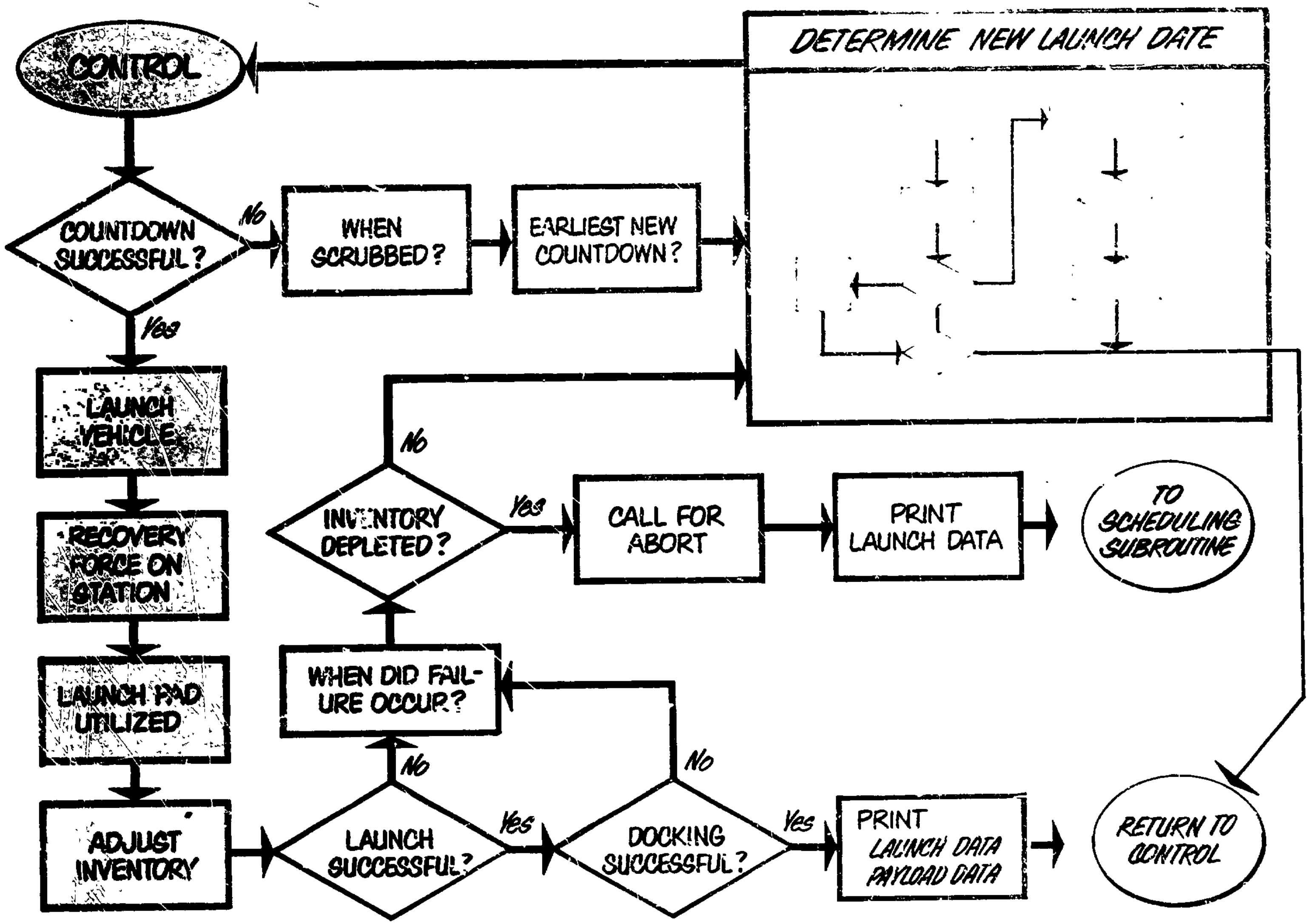


Figure 8-5

8.5.5 Special Logistics Launches

One of the key features of the Simulation Mode is its capability to process unscheduled logistics launches. A contingency or a series of contingencies may generate requirements which necessitate a modification of the planned logistics launch profile. Situations which generate such a requirement are as follows:

1. A Major Crew Illness - A crewman must be returned to earth immediately and hospitalized (see Crew Illness).
2. An Unspared Critical Failure - A spare must be shipped to avoid an abort (see Contingency Analysis).
3. A Significant Decrease in Efficiency - A series of unspared failures may lower the station efficiency sufficiently that a special resupply is warranted (see Station Efficiency).

8.5.5.1 Types of Special Launches - Two types of modifications to the launch request profile may be made by the model during simulation. The next scheduled launch may be moved up or an additional launch may be interposed in the profile. Several factors are considered in determining which course of action to follow:

- The amount of time remaining until the next scheduled launch
- The type of module scheduled on the next launch

- The situation generating the requirement
- Additional pending requests for launch profile modification.

If the type of module scheduled for the next launch is capable of satisfying the contingency requirements, and if the time of the request is within an input cut-off point of the next launch, that launch is moved up to satisfy the requirements. Otherwise, a new launch will be added to the profile. If a launch is added, the next scheduled launch may be delayed because of vehicle availability requirements, etc. (See Logistics Launch Vehicle Availability).

8.5.5.2 Payload for Special Launches - If a regularly scheduled launch is moved up to satisfy a special launch request, priority is given to the contingency requirements initiating the request. After these have been satisfied, the remainder of the payload capacity is allocated to satisfying other requirements (i.e., packaging proceeds as on a regular launch). A dynamic "want list" of spares is carried by the inventory section, and if lack of a spare or spares has initiated the special launch, all the spares on this list are ordered. If the special launch resulted from crew illness and spares may be shipped on the module type scheduled, the spares on the want list are also included in the payload.

If an additional launch is interposed to satisfy the contingency requirements, all the spares on the want list are shipped.

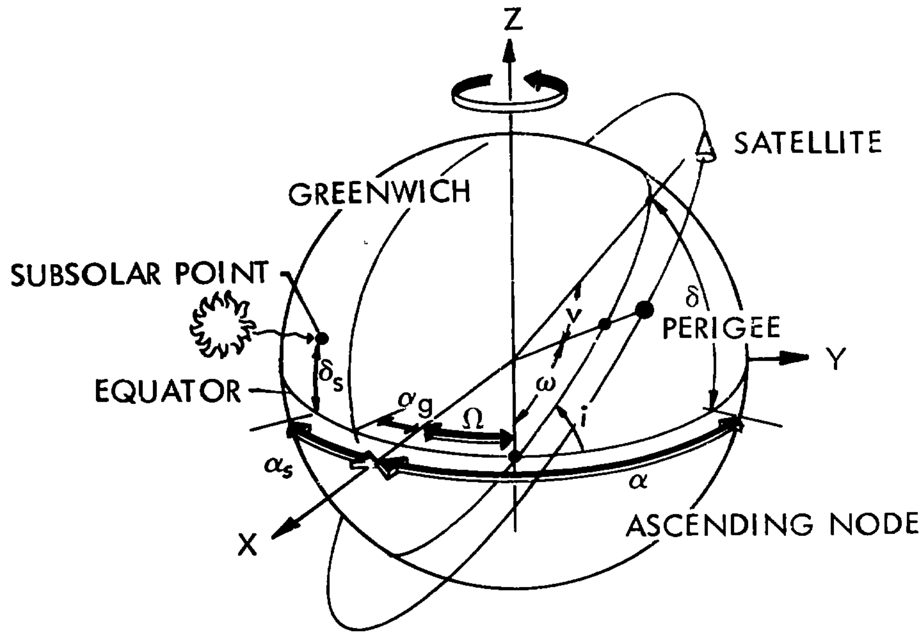
Crewmen are shipped if crew illness initiated the special launch request. However, because of the emergency nature of the launch, the remainder of the payload capacity remains unused.

8.5.6 Flight Mechanics Subroutine

The flight mechanics subroutine is used to describe the two-body motion of the space station in its circular orbit about the Earth and the logistics vehicle in its elliptical transfer orbit. This subroutine provides an approximation of the time history of the satellites' positions and velocities. The general orbital geometry associated with the flight mechanics subroutine is illustrated in Figure 8-6.

The overall structure and key concepts of the flight mechanics subroutine are illustrated in Figure 8-7. The orbital geometry associated with each of the two general computational options is also shown. These options are (1) logistics vehicle launch and rendezvous with the space station and (2) time/position of the space station. The problem data required for either option are the space station initial conditions: (1) orbital elements (size, shape, orientation of the orbit; and location of the space station in the orbit) and (2) the initial time.

8.5.6.1 Launch/Rendezvous Option - The launch/rendezvous option is used to compute launch and rendezvous data for logistics vehicles



i = Orbital inclination
Ω = Right ascension of ascending node
ω = Argument of perigee
v = True anomaly
α, δ = Right ascension, declination of satellite
α_s, δ_s = Right ascension, declination of sun
α_g = Right ascension of Greenwich meridian

Figure 8-6 ORBITAL GEOMETRY USED IN THE FLIGHT MECHANICS ROUTINE

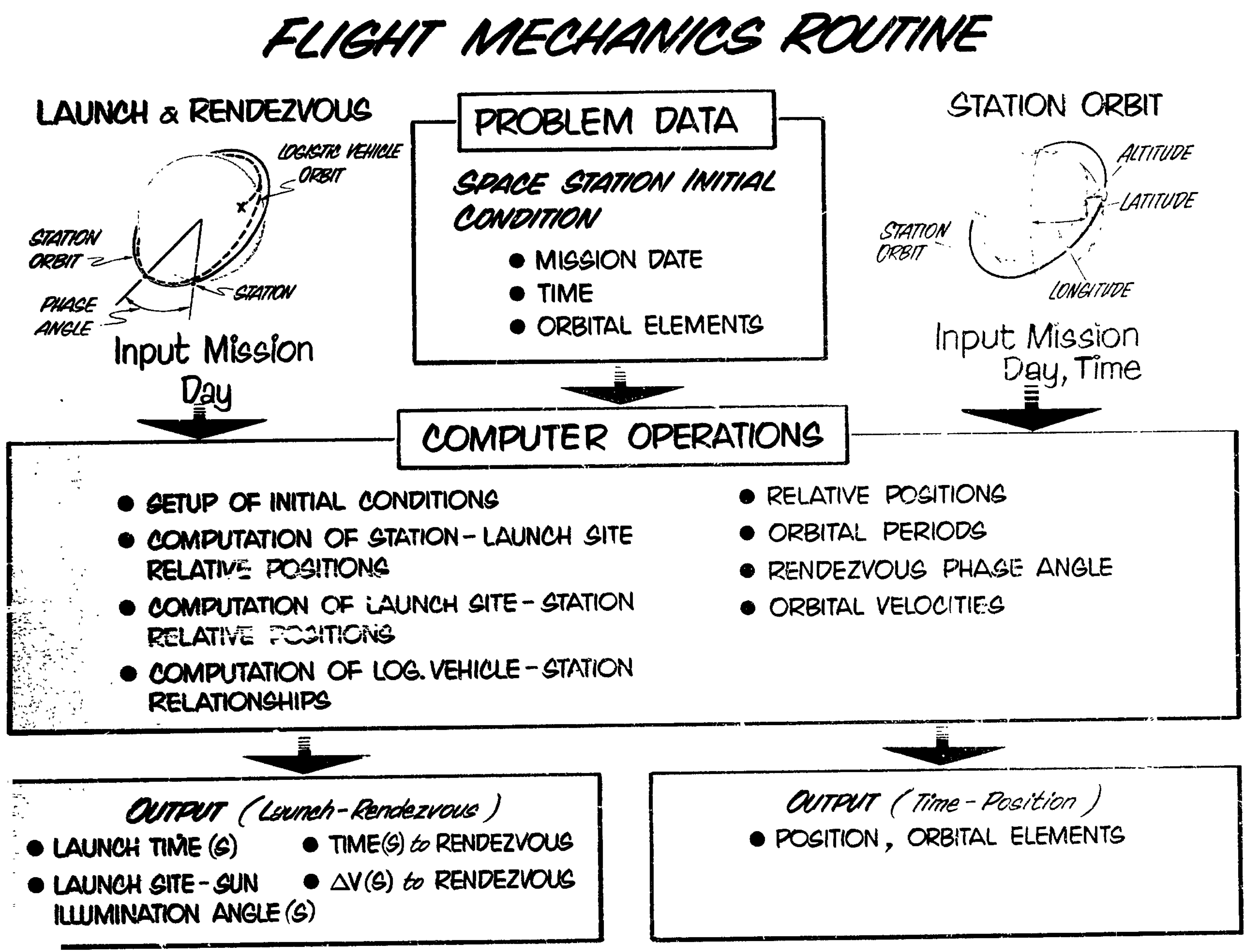

FLIGHT MECHANICS ROUTINE
LAUNCH & RENDEZVOUS
LOGISTIC VEHICLE ORBIT
STATION ORBIT
STATION
PHASE ANGLE
Input Mission Day
PROBLEM DATA
SPACE STATION INITIAL CONDITION
● MISSION DATE
● TIME
● ORBITAL ELEMENTS
STATION ORBIT
ALTITUDE
LATITUDE
STATION ORBIT
LONGITUDE
Input Mission Day, Time
COMPUTER OPERATIONS
● SETUP OF INITIAL CONDITIONS
● COMPUTATION OF STATION - LAUNCH SITE RELATIVE POSITIONS
● COMPUTATION OF LAUNCH SITE - STATION RELATIVE POSITIONS
● COMPUTATION OF LOG. VEHICLE - STATION RELATIONSHIPS
● RELATIVE POSITIONS
● ORBITAL PERIODS
● RENDEZVOUS PHASE ANGLE
● ORBITAL VELOCITIES
OUTPUT (Launch-Rendezvous)
● LAUNCH TIME (S)
● TIME(S) to RENDEZVOUS
● LAUNCH SITE - SUN ILLUMINATION ANGLE (S)
● ΔV(S) to RENDEZVOUS
OUTPUT (Time - Position)
● POSITION, ORBITAL ELEMENTS

Figure 8-7

launched from ETR into the orbit plane of the space station. The specific input for this option is time (in terms of mission day). Beginning with the mission day and the initial conditions, the following data will be computed:

1. Logistics vehicle launch opportunities - A launch opportunity is defined as the time at which the launch site (ETR) is on the space station orbit ground track.
2. Launch site illumination angles at launch opportunities - The illumination angle is defined as the angle between the subsolar point and the launch site (see Figure 8-7). Right ascension of the subsolar point is computed as a function of the Earth's average orbital motion (assumed constant).
3. Time (from launch) required for the logistics vehicle to rendezvous with the space station - The total time is computed as the sum of the time from launch to injection into a 100 n.mi. parking orbit (assumed constant) and the computed time to effect a Hohmann transfer and rendezvous with the space station. Waiting time to rendezvous is assumed to occur in the transfer orbit, rather than in the parking orbit, and rendezvous is assumed to occur when a minimum phase angle (see Figure 8-7) is computed with the logistics vehicle at apogee of

the transfer ellipse. This method approximates a gross rendezvous maneuver and does not include time for the terminal rendezvous maneuver.

4. Total ΔV required to rendezvous with the space station. The total ΔV is computed as the sum of the incremental velocities required to effect a Hohmann transfer from the 100 n.mi. parking orbit to the space station circular orbit and circularize into the space station orbit.

If the launch site is in darkness at the first launch opportunity (illumination angles greater than 90°), conditions of successive launch and rendezvous opportunities are computed until a daylight launch opportunity is achieved when the daylight launch window option is selected.

8.5.6.2 <u>Time/Position Option</u> - The time/position option of the flight mechanics subroutine is used to compute the space station position corresponding to a specific input time (in terms of mission day). This is accomplished by solving Kepler's equation by iteration, with time as the independent variable. The line-of-nodes precession rate used in this option is approximated as a function of the orbit radius and the second gravitational harmonic. Position of the subsatellite point is computed with respect to both a right ascension-declination coordinate system and the Earth latitude-longitude system.

9.0 SCHEDULING OF EVENTS

9.1 Introduction

The function of the scheduling routine is to schedule crew activities and mission events to provide a time-ordered mission plan. The primary objectives to be accomplished by the Scheduling Routine (see Figure 9-1) include the following:

1. Assessment of resource requirement magnitudes and distributions
2. Determination of expected rate of mission accomplishment
3. Determination of program length and magnitude
4. Determination of mission accomplishment rate sensitivity to various crew mixes and levels of crew cross-training.

In addition, scheduling of random events in the Simulation Mode should permit (1) determination of probable deviation from initial plans, (2) specific case studies, (3) formulation of special procedures, and (4) use of the model as a training aid.

Scheduling, as used herein, implies determination of the time at which each experiment and task should be initiated, based upon mission-related value criteria and constraints. The scheduling process, then, is essentially a series of repetitious tests to select an event, then determine whether or not that particular event can be started and successfully concluded within a given set of resource constraints.

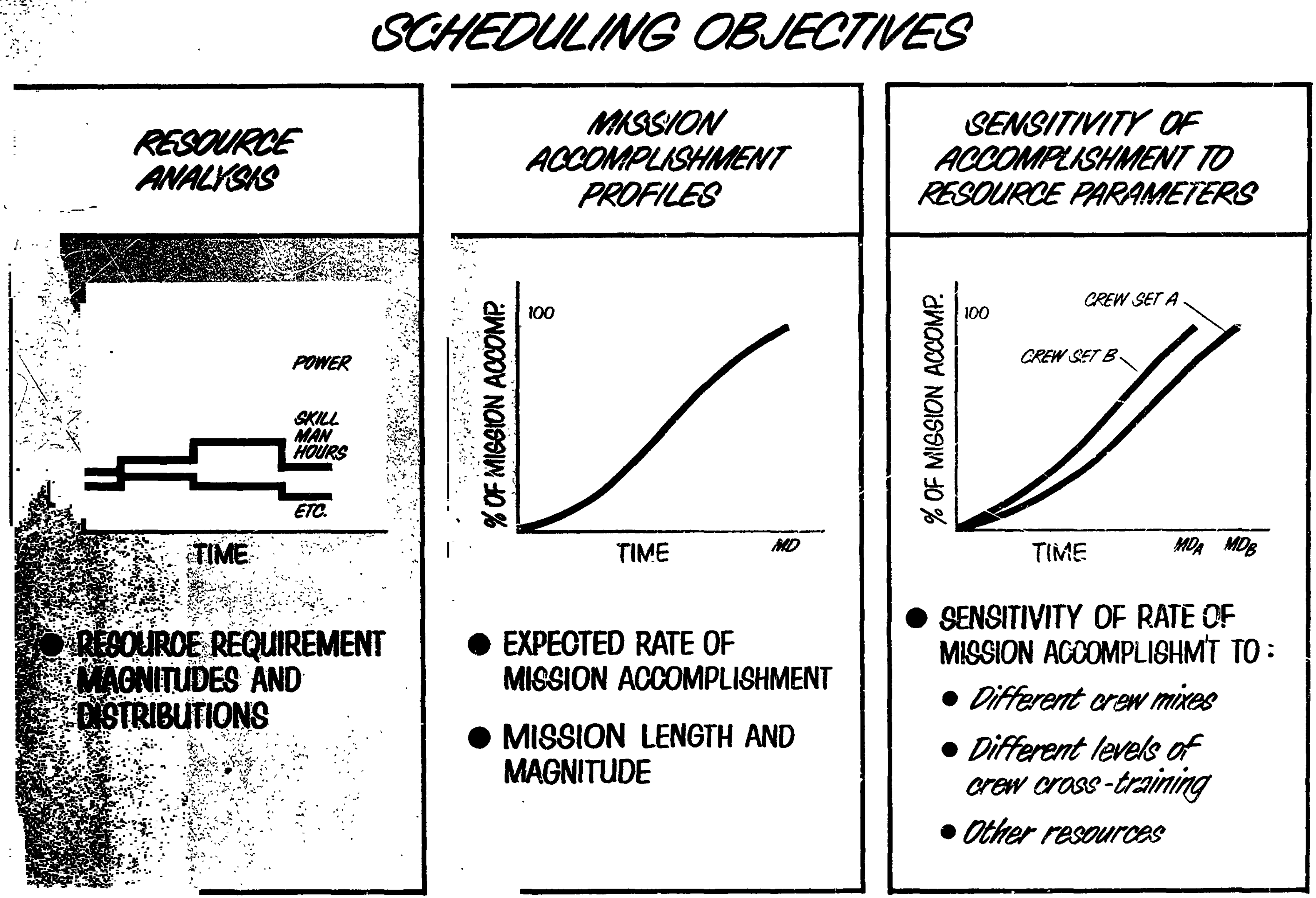

SCHEDULING OBJECTIVES
RESOURCE ANALYSIS
POWER
SKILL MAN HOURS
ETC.
TIME
RESOURCE REQUIREMENT MAGNITUDES AND DISTRIBUTIONS
MISSION ACCOMPLISHMENT PROFILES
% OF MISSION ACCOMP.
100
TIME
MD
EXPECTED RATE OF MISSION ACCOMPLISHMENT
MISSION LENGTH AND MAGNITUDE
SENSITIVITY OF ACCOMPLISHMENT TO RESOURCE PARAMETERS
% OF MISSION ACCOMP.
100
CREW SET A
CREW SET B
TIME
MDA MDB
SENSITIVITY OF RATE OF MISSION ACCOMPLISHM'T TO:
Different crew mixes
Different levels of crew cross-training
Other resources

Figure 9-1

9.2 Scheduling Approach

In this study, the general approach to scheduling (see Figure 9-2) has been to schedule events to fit into discrete time intervals and, although a 24-hour time interval is currently used for problem checkout, the model is constructed so that the time interval can be reduced to any desired level. Data currently being used do not justify scheduling on an interval smaller than an 8-hour work shift. Similarly, detailed time-lining is not necessary to satisfy the general purpose of the present model; hence, the events are not time-lined within the scheduling-time intervals. Each task is started as soon as the preceding task is finished, thus obtaining maximum utilization of the crew's time within the time intervals (see Subsection 9.5.1).

The analytical approach has been divided into the three phases shown in Figure 9-2. In the data analysis phase, the necessary event descriptors were determined and a general format was developed for inputing them. Development of the scheduling logic has been accomplished through a building block approach. A general scheduling subroutine (GSS), itself composed of well-defined subroutines (such as resource updating, etc.), has been developed, and is used extensively to perform the actual scheduling and bookkeeping. Control programs (see Figure 9-3) have been

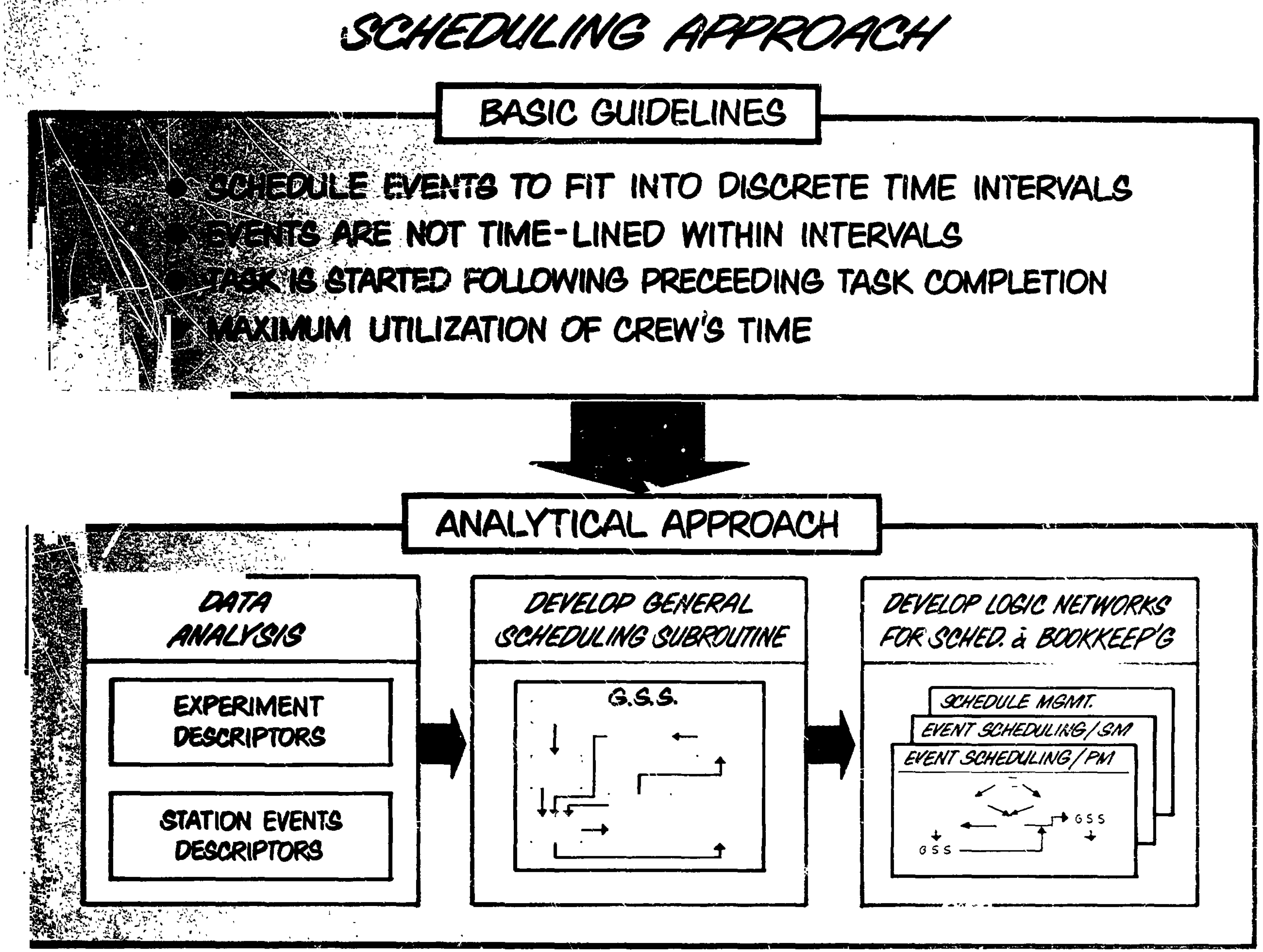

SCHEDULING APPROACH
BASIC GUIDELINES
• SCHEDULE EVENTS TO FIT INTO DISCRETE TIME INTERVALS
• EVENTS ARE NOT TIME-LINED WITHIN INTERVALS
• TASK IS STARTED FOLLOWING PRECEEDING TASK COMPLETION
• MAXIMUM UTILIZATION OF CREW'S TIME
ANALYTICAL APPROACH
DATA ANALYSIS
EXPERIMENT DESCRIPTORS
STATION EVENTS DESCRIPTORS
DEVELOP GENERAL SCHEDULING SUBROUTINE
G.S.S.
DEVELOP LOGIC NETWORKS FOR SCHED. & BOOKKEEP'G
SCHEDULE MGMT.
EVENT SCHEDULING/SM
EVENT SCHEDULING/PM
GSS
GSS

Figure 9-2

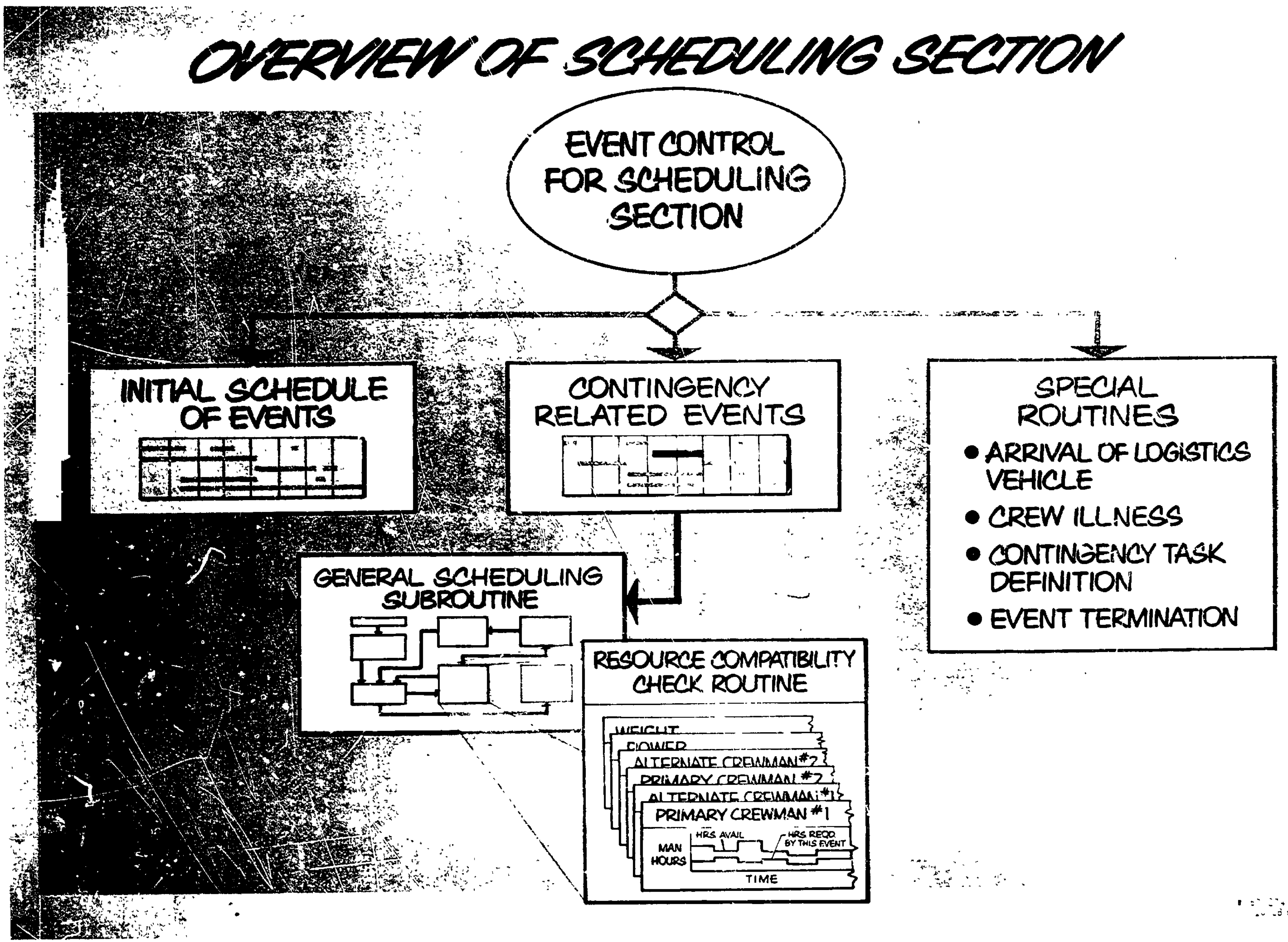

OVERVIEW OF SCHEDULING SECTION
EVENT CONTROL FOR SCHEDULING SECTION
INITIAL SCHEDULE OF EVENTS
CONTINGENCY RELATED EVENTS
SPECIAL ROUTINES
• ARRIVAL OF LOGISTICS VEHICLE
• CREW ILLNESS
• CONTINGENCY TASK DEFINITION
• EVENT TERMINATION
GENERAL SCHEDULING SUBROUTINE
RESOURCE COMPATIBILITY CHECK ROUTINE
PRIMARY CREWMAN #1
HRS AVAIL
HRS REQD BY THIS EVENT
MAN HOURS
TIME

Figure 9-3

developed which use the general scheduling subroutine (GSS) to accomplish the following:

1. Determine the initial schedule of events
2. Schedule contingency-related events
3. Reschedule any events which were interrupted by the contingency.

In addition to these primary functions the scheduling section of the Space Station Model contains special subroutines to define and/or schedule tasks associated with (1) logistics vehicle arrival, (2) crew illness, (3) contingencies task definition, and (4) event termination.

An overall event control program for the scheduling section controls the calling sequence of the various scheduling routines and handles all communication with the event control program of the primary model.

9.3 Functions of the Scheduling Section

9.3.1 Initial Scheduling of Events

The first function of scheduling, the initial scheduling of events (see Figure 9-4), is based upon expected values for all random variables. The resultant program plan subsequently is modified as contingencies occur.

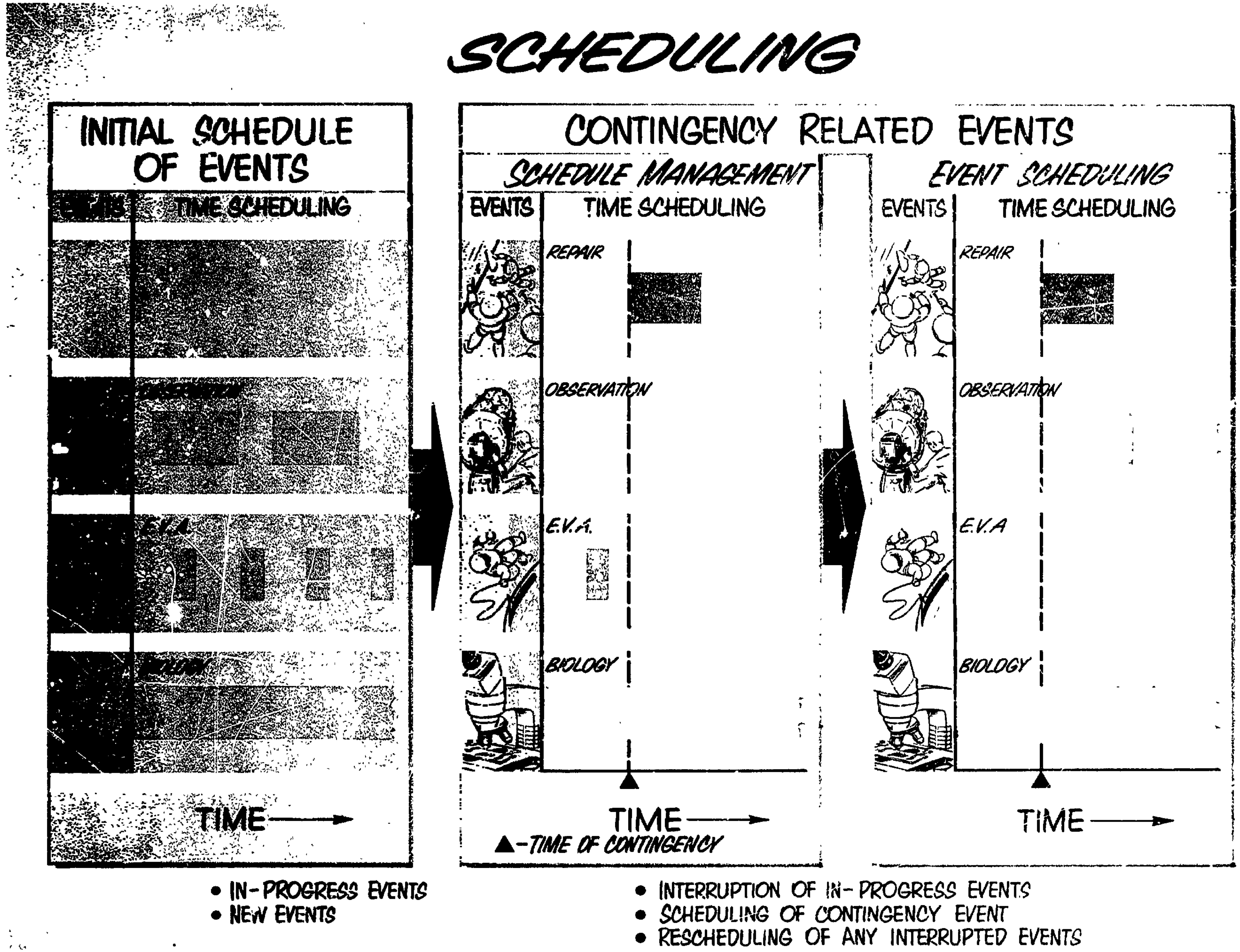

SCHEDULING
INITIAL SCHEDULE OF EVENTS
TIME SCHEDULING
TIME
• IN-PROGRESS EVENTS
• NEW EVENTS
CONTINGENCY RELATED EVENTS
SCHEDULE MANAGEMENT
EVENTS
TIME SCHEDULING
REPAIR
OBSERVATION
E.V.A.
BIOLOGY
TIME
▲-TIME OF CONTINGENCY
EVENT SCHEDULING
EVENTS
TIME SCHEDULING
REPAIR
OBSERVATION
E.V.A
BIOLOGY
TIME
• INTERRUPTION OF IN-PROGRESS EVENTS
• SCHEDULING OF CONTINGENCY EVENT
• RESCHEDULING OF ANY INTERRUPTED EVENTS

Figure 9-4

The in-progress station-keeping tasks are scheduled first by the general scheduling subroutine (GSS) and are followed by any new tasks for the current period. In-progress and new experiments are next scheduled, using the same process. As the events are scheduled, the lengths of any interruptions of the in-progress events are recorded. At the end of the current period any uncompleted events are written on tape as in-progress events for the next period.

In actually scheduling the sets of station-keeping tasks and experiments within the general scheduling subroutine, the following steps are performed:

1. Determination of priorities
2. Search and initial screening
3. Resource compatibility check and modification of available resource matrix
4. Bookkeeping.

9.3.2 Contingency Related Events

The process of scheduling contingency-related events and subsequent rescheduling of any interrupted events is also illustrated in Figure 9-4. These adjustments and schedule changes in the Space Station Model are accomplished by two subroutines: schedule management and event scheduling. Each of the subroutines uses the GSS extensively to schedule and perform resource bookkeeping.

The schedule management subroutine is responsible for interrupting in-progress experiments and tasks and for scheduling contingency tasks which are generated by the station operations routine. The contingency tasks are those tasks necessary to repair, correct, or account for random occurrences. An attempt is made to schedule the contingency task, within a given critical time constraint if necessary, without interrupting in-progress events. If this attempt fails, experiments are interrupted from occurrence of the random event until the end of this launch period; then, another attempt is made to schedule the contingency task. If the second attempt is also unsuccessful, all station-keeping tasks which can be interrupted are interrupted, and a final attempt is made to schedule the contingency task. When the task has been scheduled, the model control proceeds to the event-scheduling subroutine.

If the contingency task remains unscheduled, a check is made to see if a critical scheduling time constraint was given. If a critical time constraint has been given, an abort situation exists. If a critical time constraint is not given, the resource-availability profiles are updated to reflect the losses associated with this event. Control is then shifted to the event-scheduling subroutine.

The purpose of the event-scheduling subroutine is to reschedule all experiments and tasks which have been interrupted by the schedule management subroutine. In this procedure a temporary high value is assigned to those events which will sustain a loss of data during the time they are interrupted. This causes the general scheduling subroutine to reschedule these events at the earliest possible time.

9.4 Special Subroutines

In the development of the scheduling section of the Space Station Model certain special purpose subroutines are necessary. These subroutines (illustrated in Figure 9-3) are responsible for the definition and/or the scheduling of particular types of tasks.

9.4.1 Scheduling of Tasks Associated with the Arrival of Logistics Vehicle

A series of tasks must be performed by the crewmen at the time of arrival of each logistics vehicle. These tasks include:

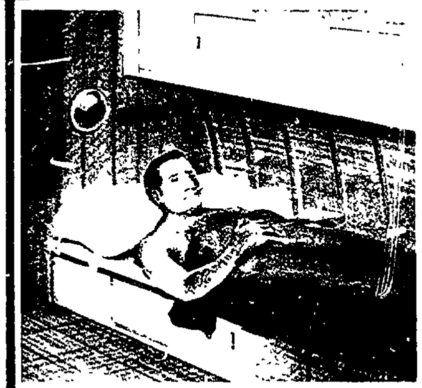
1. Rendezvous and docking
2. Unloading of supplies
3. Storage of multimission module
4. Repairs requiring use of spares brought aboard.

Basic descriptions for the tasks listed above are contained in the crew task library of the station operations routine. These task descriptions are input into the scheduling section and the tasks are then scheduled. In the Simulation Mode, crew overtime

SPECIAL ROUTINES FOR SCHEDULING IN THE SIMULATION MODE

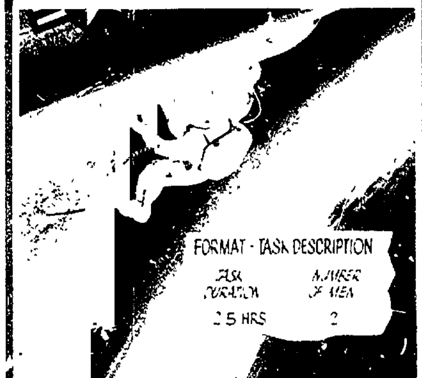
ARRIVAL OF LOGISTICS VEHICLE

- Rendezvous and docking
- Unloading
- Stowage of MMM
- Crew transfer



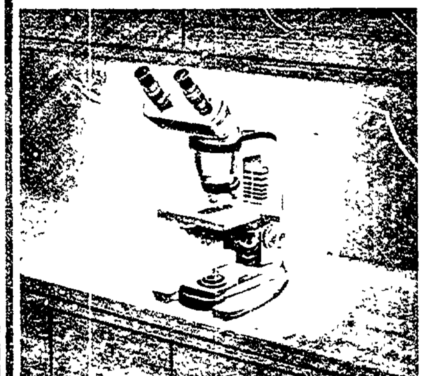
CREW ILLNESS

- Minor - Reduce work load
- Major - Remove crewman from scheduling inventory



CONTINGENCY TASK DEFINITION

- Description of task from station operations library
- Load into scheduling format



EVENT TERMINATION
(Random completion events)

- Incubation period in zero-G environment

FW 67 2/4 9454 10 28 67

Figure 9-5

and interruption of in-progress events are allowed in the scheduling of tasks associated with the arrival of the logistics vehicle.

The scheduling inventory of crewmen on board also must be updated to reflect any change in crew. Since a normal logistics arrival signals the beginning of a new launch period interval, inventories are updated automatically, and a new schedule is then generated. However, for a special logistics shot a check must be made to determine if crewmen have previously been sent down because of a major illness. The scheduling inventory must be updated to indicate the arrival of crew replacements aboard the special launch, and a new schedule must be generated from the time of replacement arrival to the end of the current lauch-period interval.

9.4.2 Scheduling of Crew Illness

Several tasks must be accomplished by the scheduling section to reflect crew illness correctly. Tasks corresponding to each crew illness must be defined; these tasks are then scheduled at the appropriate times.

When a minor illness occurs, a task is defined which requires all of the available time of the sick crewman for the next two days. This task is given top priority and is scheduled in the same manner as other contingency tasks. After the special task is scheduled, events are rescheduled for the remainder of the current launch period to allow the crewman to resume his normal tasks at the end of the two-day period.

In the event of major illness, the sick crewmen must be sent down for hospitalization. Therefore, when a major illness occurs, a task is defined which will consume all of the time of the sick crewman and all of the time of the two crewmen who must ferry the sick man back to earth. The defined task is then scheduled to last from the current date to the end of the launch period. This task scheduling effectively removes the three crewmen from the scheduling inventory, since they will no longer be available for other tasks or experiments. Upon arrival of a crew vehicle, rescheduling at the new crew level will occur. Aspects of crew illness are discussed in detail in Subsection 6.4 of this report.

9.4.3 Contingency Task Loading Subroutine

The use of a standard format for the description of all types of scheduled events permits use of the same scheduling subroutine for scheduling station-keeping tasks, experiments, and contingency-related tasks. Descriptions of the station-keeping tasks and experiments can be coded and input in this standard format; however, it has proved inefficient to store repair tasks in this general format. Therefore, the scheduling section provides a subroutine which, at the time of a failure, can take the abbreviated description of the repair task from the station operations task library and load this description into the general format required by the scheduling routine. This subroutine has the capability to generate, as necessary, any additional data required to fill the larger format.

9.4.4 Event Termination

The space station model allows durations of random lengths in as many as 40 experiments. Inputs for these experiments include an optimistic, a pessimistic, and an expected duration. In the initial scheduling of events, the scheduling section uses the expected duration for these random-keyed experiments. Once scheduled, the start dates and expected durations determine the expected completion dates for these experiments (see Figure 9-6). In the Simulation Mode the random events generator determines the actual completion dates of some experiments and enters these dates in the event table.

If the actual duration of a random-keyed experiment is greater than the expected duration, a delta-task (see Figure 9-6) must be defined which describes that portion of the experiment which takes place from the time of expected completion to the actual completion date. This delta-task can then be scheduled to begin at the expected completion date. Once this delta-task is scheduled, the amount of time and other resources used on this experiment will be correctly represented in the scheduling resource inventories.

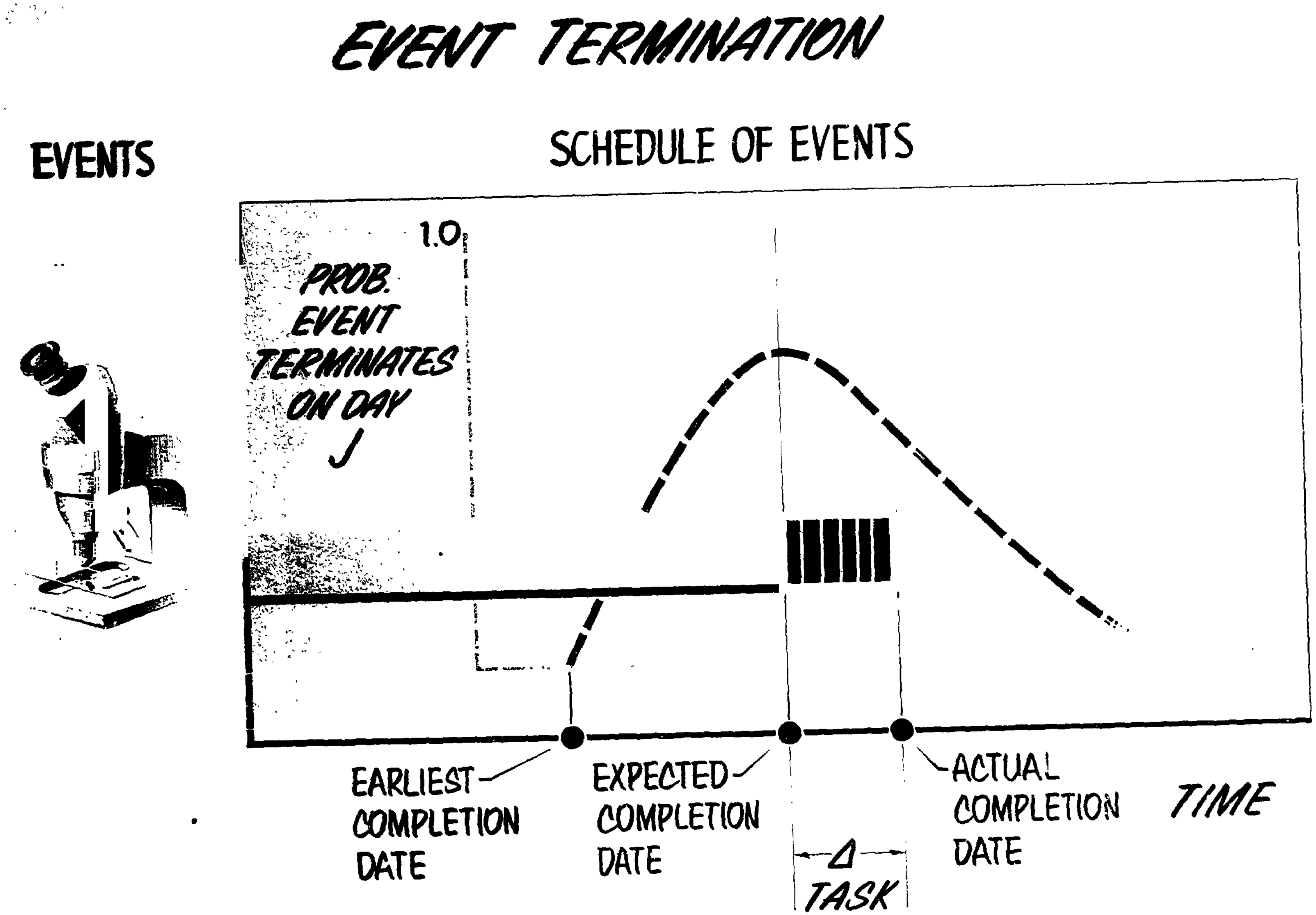

EVENT TERMINATION
EVENTS
SCHEDULE OF EVENTS
1.0
PROB. EVENT TERMINATES ON DAY J
EARLIEST COMPLETION DATE
EXPECTED COMPLETION DATE
ACTUAL COMPLETION DATE
Δ TASK
TIME

Figure 9-6

If the actual duration of a random-keyed experiment is less than the expected completion date, two courses of action are possible. If the difference between the expected and actual completion dates is less than a certain control variable (the value of which is an input number, i.e., 3 days), the scheduling section will update its resource inventories to indicate the correct, early completion date of the experiment.

If the difference between the expected and actual completion dates is greater than the control variable, the scheduling section also will update its inventories to show the early completion. In this case, however, all experiments starting after the actual completion date of this random-keyed experiment are rescheduled to take advantage of the additional resources made available by the early completion.

9.5 Description of the General Scheduling Subroutine (GSS)

The actual scheduling of events and resource bookkeeping, as previously indicated, is performed by the general scheduling subroutine (GSS). Detailed characteristics and capabilities of the GSS are shown in Figure 9-7.

9.5.1 Basic Concept

Mission durations range from less than 90 days to several years. Consideration of the trade-off involved in level of

CHARACTERISTICS AND CAPABILITIES OF THE GENERAL SCHEDULING ROUTINE (GSS)

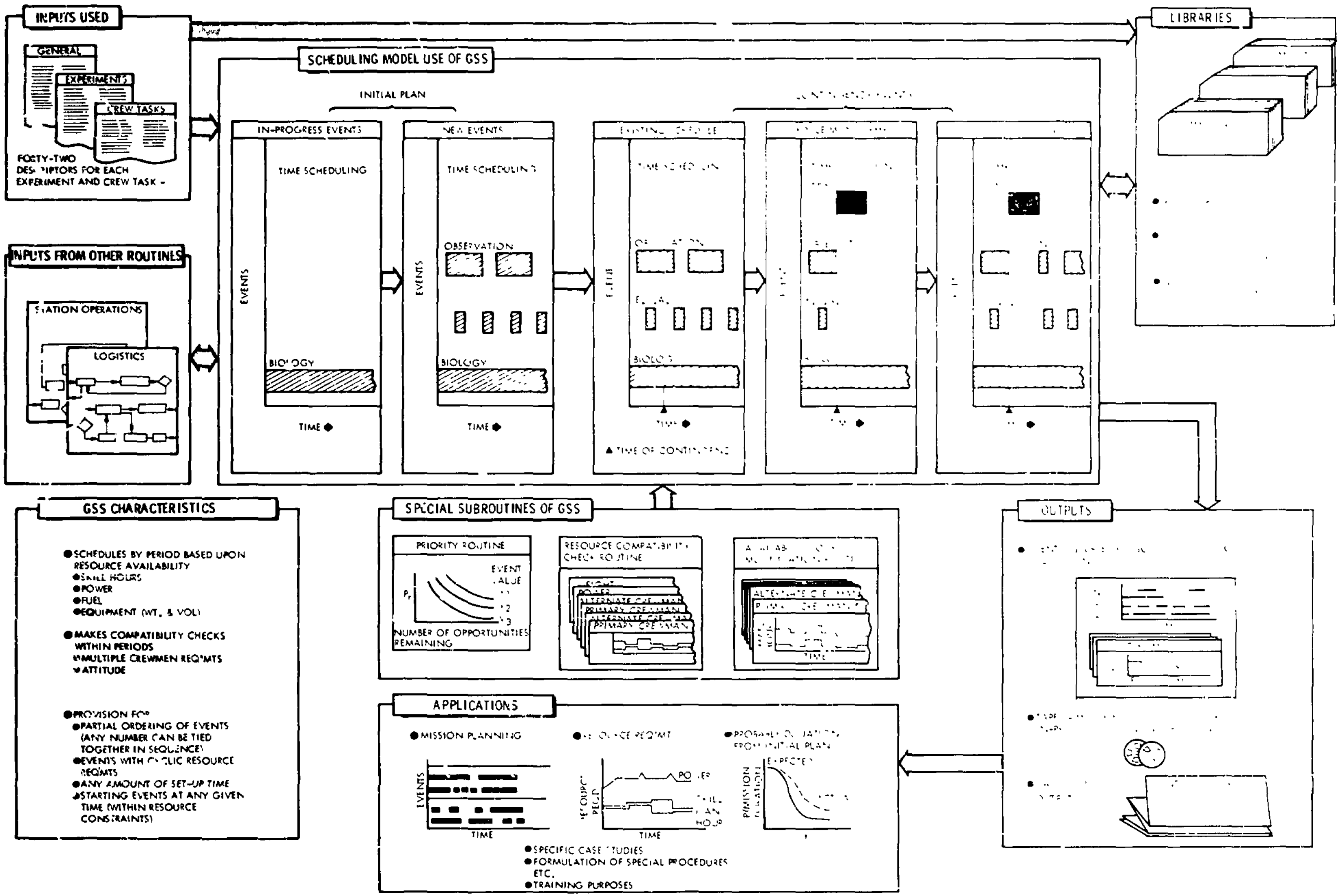


Figure 9-7

scheduling detail, degree of accuracy in available input data, and optimum use of existing computer systems, has determined a need for a scheduling concept different from that used by current scheduling models designed specifically for short-duration missions.

A generalized scheduling methodology, based upon scheduling by discrete time intervals (8-hour shifts, 24-hour periods, etc.) has been developed and applied in the general scheduling subroutine (GSS). The level of scheduling detail can be varied by changing the scheduling interval. Thus, for almost any conceivable space mission, a balance can be reached between (1) scheduling detail, (2) duration of mission, (2) accuracy of input data, and (4) machine limitations.

For example, if the mission being considered has a relatively long duration (e.g., one to two years), machine limitations will probably necessitate the use of a 24-hour scheduling-time interval. If the mission duration is shorter and a higher level of scheduling detail is desired, the scheduling interval can be decreased to 8 hours, 4 hours, or even lower, if machine storage permits.

Computer storage requirements depend directly upon the total number of scheduling-time intervals processed. Thus, a 300-day mission with 24-hour intervals requires approximately the same storage as a 100-day mission scheduled with 8-hour intervals.

The size of the scheduling interval is the smallest range of time into which events are placed. For example, printout indicating that events 12, 8, 23, and 37 start during interval 96 (or are in progress during interval 96) is typical of the output generated by the GSS. No particular order of events is assumed within the interval. The output basically provides each crewman with a work list for each interval.

9.5.2 GSS Program Logic

The general scheduling subroutine, in conjunction with various control programs, allows the following scheduling options:

1. Fixed priorities or dynamic priorities (where priority is a function of experiment value and number of opportunities remaining to perform experiment)
2. Fixed experiment completion dates or probabilistic completion dates with rescheduling
3. No random events or random events with rescheduling.

Within the GSS provision is made for:

1. Partial ordering of experiments (i.e., any number of experiments can be tied together in sequence)
2. Experiments with cyclic resource requirements
3. Experiments requiring any amount of set-up time
4. Experiments which must be performed or started on a given day of the mission.

Checks are performed in the model to ensure compatibility with spacecraft orientation and to ensure that any required special equipment is available before an experiment is scheduled.

Figure 9-8 represents the detailed logic for use of the GSS to perform primary scheduling functions in the Space Station Model. The dashed lines indicate the points in the model at which the GSS functions.

The GSS (Figure 9-9) has been programmed to accept as input data (1) a list of event descriptors, (2) a span of time (stated as a number of scheduling intervals), and (3) a subset (which may be the entire set) of events to be scheduled. The assignment of events to crewmen has also been programmed as an input to this subroutine. This was done to utilize the crew skill-mix selection and the assignment of events to crewmen accomplished in the Preliminary Requirements Model (PRM). However, provision for limited reassignment of events to alternate crewmen is included in the scheduling routine.

For each time interval in the input time span the priority of each event to be scheduled is determined using the equation

$$\text{Priority} = V/X^2$$

where

V = the input value of each event
(V is set; automatically = 1 if not input)

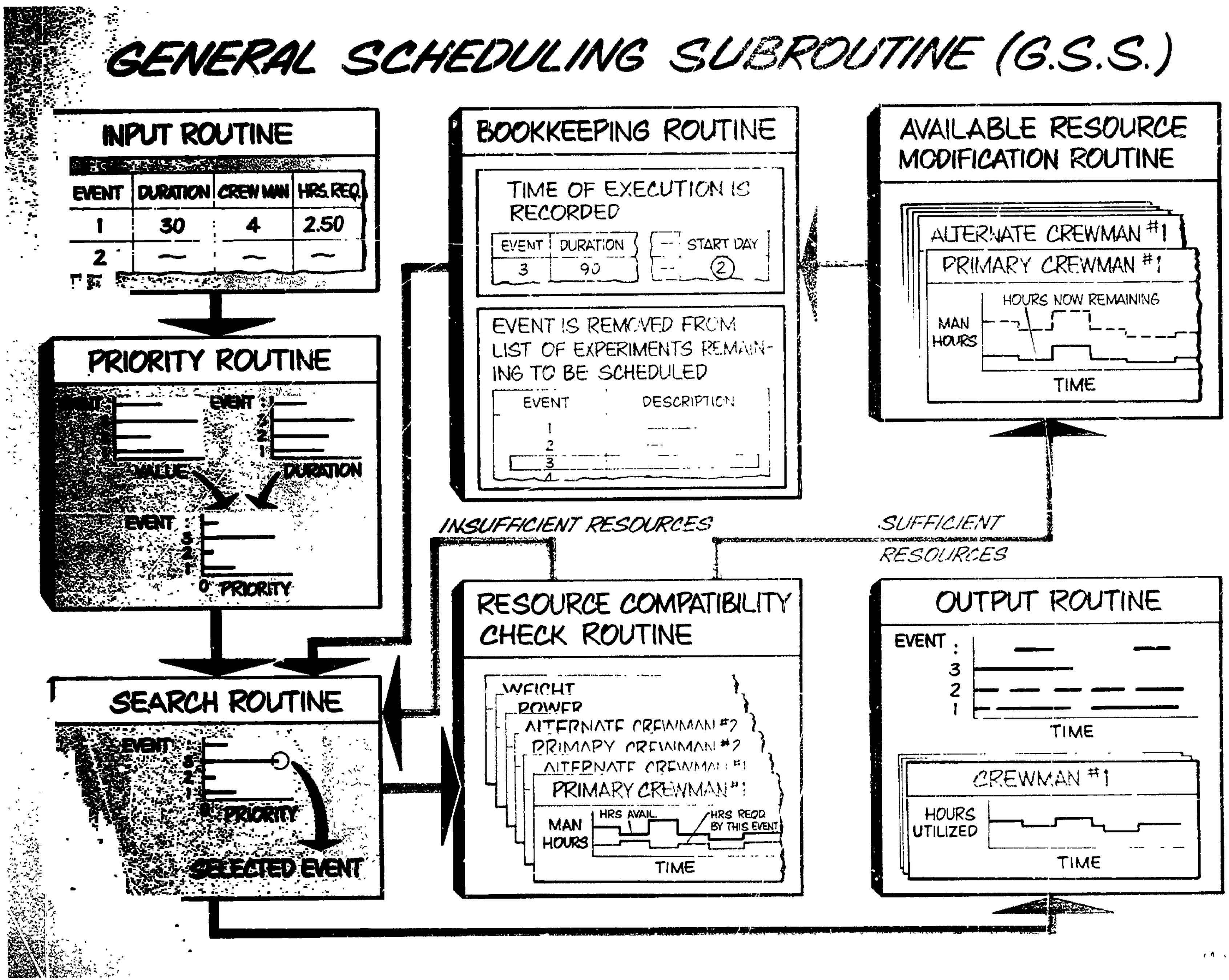

GENERAL SCHEDULING SUBROUTINE (G.S.S.)
INPUT ROUTINE
EVENT
DURATION
CREW MAN
HRS. REQ.
1
30
4
2.50
2
PRIORITY ROUTINE
EVENT
VALUE
DURATION
PRIORITY
SEARCH ROUTINE
SELECTED EVENT
BOOKKEEPING ROUTINE
TIME OF EXECUTION IS RECORDED
EVENT
DURATION
START DAY
3
90
2
EVENT IS REMOVED FROM LIST OF EXPERIMENTS REMAINING TO BE SCHEDULED
DESCRIPTION
AVAILABLE RESOURCE MODIFICATION ROUTINE
ALTERNATE CREWMAN #1
PRIMARY CREWMAN #1
HOURS NOW REMAINING
MAN HOURS
TIME
INSUFFICIENT RESOURCES
SUFFICIENT RESOURCES
RESOURCE COMPATIBILITY CHECK ROUTINE
WEIGHT
POWER
ALTERNATE CREWMAN #2
PRIMARY CREWMAN #2
ALTERNATE CREWMAN #1
PRIMARY CREWMAN #1
HRS AVAIL.
HRS REQD BY THIS EVENT
OUTPUT ROUTINE
CREWMAN #1
HOURS UTILIZED

Figure 9-8

LOGIC FOR USE OF GSS

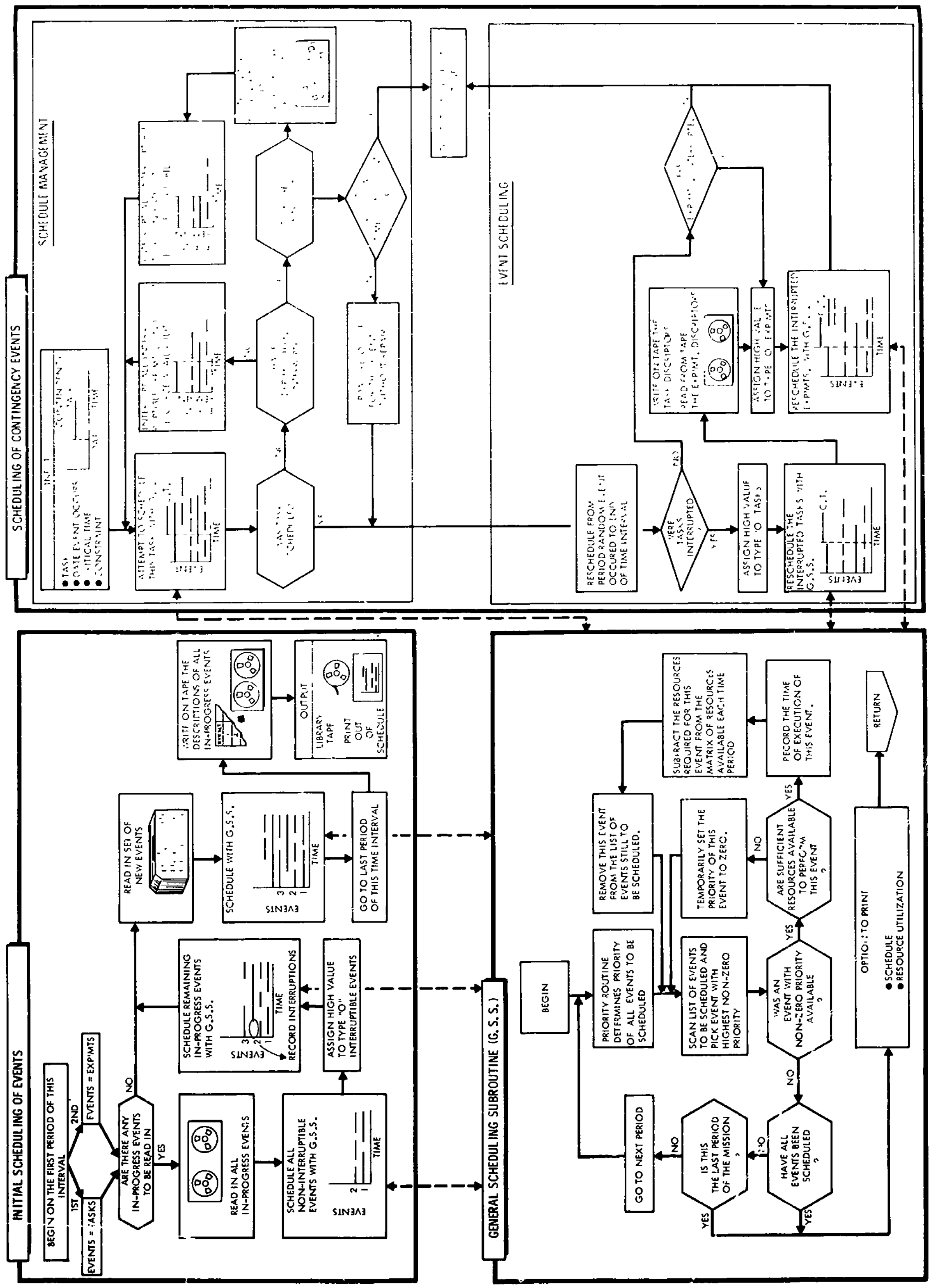


Figure 9-9

X = the number of opportunities remaining for scheduling this event.

This relationship is easily changed or replaced, if desired, by inputing fixed priorities for each event. The events are scanned and the task with the highest priority is selected; a check is then made to see if the necessary resources for that event are available. If resources are available, the execution time for the event is recorded, and resources used by the event are subtracted from the resources available for new events. If resources are not available, the event with the next highest priority is selected, and an attempt is made to schedule it. This procedure is repeated until all events are scheduled or until the end of the last interval is reached.

10.0 STATION OPERATIONS

10.1 General

The purpose of the station operations routine is to determine the portion of available resources required to support the station. These resource requirements include laboratory subsystem loading, crew utilization, and logistics requirements. When these requirements have been satisfied, the remaining resources can be used for support of the experimental programs. The basic concept of the station operations routine is illustrated in Figure 10-1.

In the Planning Mode, the station operation routine's major functions are (1) to maintain an inventory of the expendable supplies on board the laboratory and (2) to plan their resupply requirements. These requirements are computed from the station's nominal consumption rates and the input crew rotation plan. An optimization procedure is provided which adjusts these requirements to conform to any existing logistics system constraints. Two other inventory-related computations are made. The first is maximum stay-time (time until resupply is mandatory to avoid abort). If the maximum stay-time reflects incompatibility between the crew-rotation plan and resupply requirements for expendables, the model user is notified and the problem is terminated. The

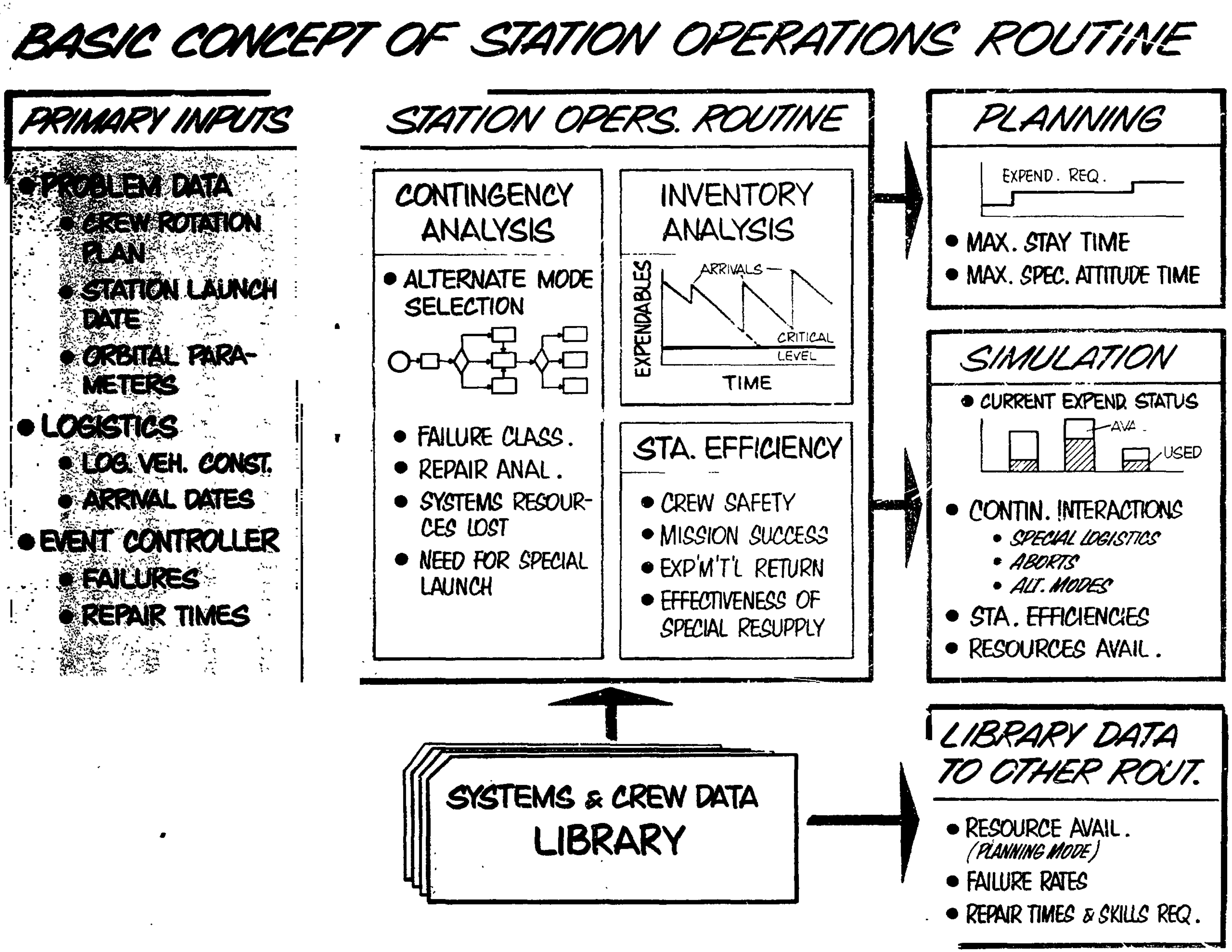

BASIC CONCEPT OF STATION OPERATIONS ROUTINE
PRIMARY INPUTS
• PROBLEM DATA
• CREW ROTATION PLAN
• STATION LAUNCH DATE
• ORBITAL PARAMETERS
• LOGISTICS
• LOG. VEH. CONST.
• ARRIVAL DATES
• EVENT CONTROLLER
• FAILURES
• REPAIR TIMES
STATION OPERS. ROUTINE
CONTINGENCY ANALYSIS
• ALTERNATE MODE SELECTION
• FAILURE CLASS.
• REPAIR ANAL.
• SYSTEMS RESOURCES LOST
• NEED FOR SPECIAL LAUNCH
INVENTORY ANALYSIS
EXPENDABLES
ARRIVALS
CRITICAL LEVEL
TIME
STA. EFFICIENCY
• CREW SAFETY
• MISSION SUCCESS
• EXP'M'T'L RETURN
• EFFECTIVENESS OF SPECIAL RESUPPLY
PLANNING
EXPEND. REQ.
• MAX. STAY TIME
• MAX. SPEC. ATTITUDE TIME
SIMULATION
• CURRENT EXPEND. STATUS
AVA.
USED
• CONTIN. INTERACTIONS
• SPECIAL LOGISTICS
• ABORTS
• ALT. MODES
• STA. EFFICIENCIES
• RESOURCES AVAIL.
LIBRARY DATA TO OTHER ROUT.
• RESOURCE AVAIL. (PLANNING MODE)
• FAILURE RATES
• REPAIR TIMES & SKILLS REQ.
SYSTEMS & CREW DATA LIBRARY

Figure 10-1

second computation, determination of the maximum time that can be spent in special orientations, is a function of the orbital parameters, calendar year under consideration, and amount of fuel on board. It is used as a constraint for scheduling experiments which require special orientation.

In the Simulation Mode, the routine performs several additional functions to process contingency events. In processing a systems failure, adjustments are made in the station status to reflect loss in resources; then, appropriate action is initiated to restore the system to its original operating condition. This action involves the definition of a repair task and may include a request for a special logistics launch, depending upon the time remaining before the next scheduled launch. The special launch may be either an early crew rotation or an additional, unscheduled launch. An abort is called if crew safety drops below tolerable levels due to failures in the logistics system or multiple station failures. The major factors which are considered in processing a contingency event include:

1. Criticality of failure
2. Spares availability
3. Other failures in the same system
4. Alternate modes and redundancy

5. Downtime constraints
6. Resources remaining
7. Repair time and skills required
8. Crew safety
9. Probability of mission success
10. Experimental return
11. Time remaining before next scheduled launch.

The last four factors are combined into an efficiency measure which is used to determine the necessity of a special logistics launch.

The systems library contains 24 descriptors for each of approximately 400 replaceable components. These descriptors are utilized by the routine throughout the processing of a contingency event.

The station operations routine has been divided into the following sections:

1. Inventory Analysis - computation of amounts of station supplies on board and amounts to be shi[illegible]
2. Contingency Analysis - adjustments nec[illegible]ry for contingency events (e.g., parts failures), updating available systems resources, modes of operation, etc.

3. Station Efficiency - computation of the efficiency of operation of the station, dependent upon probability of mission success, crew safety, and experimental return
4. Events Library - information essential to the operation of sections 1, 2 and 3, and supplemental data used by other routines
5. Aborts - management of abort situations.

10.2 Inventory Analysis

The Inventory Analysis Section operates in both the Planning and Simulation Modes. In the Planning Mode it generates, from a crew launch profile, an optimized mission-requirements profile for each expendable. Inventory levels are updated and requirements are calculated by repeating the supplies-ordering procedure once for each launch date. In addition, calculation of maximum stay-time (time until resupply is mandatory to avoid abort) and maximum time which may be spent in special orientations are performed on each iteration (see Figure 10-2).

10.2.1 Expendables Consumption Rates

For most categories of expendables, the amount used in a given time period can be computed with a simple usage-rate relationship; their derivation is discussed in the following paragraphs.

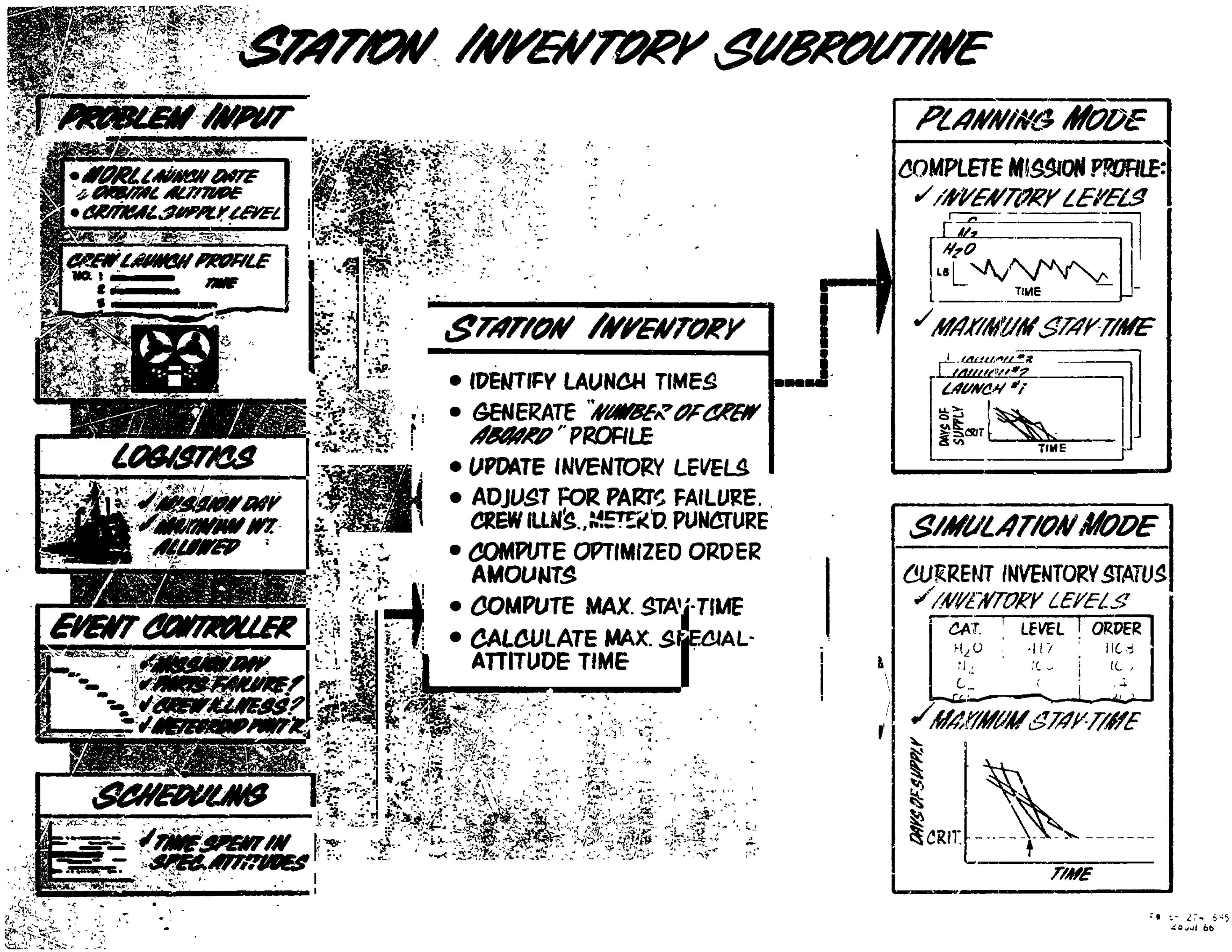

STATION INVENTORY SUBROUTINE
PROBLEM INPUT
• MORL LAUNCH DATE & ORBITAL ALTITUDE
• CRITICAL SUPPLY LEVEL
CREW LAUNCH PROFILE
NO.
TIME
LOGISTICS
✓ MISSION DAY
✓ MAXIMUM WT. ALLOWED
EVENT CONTROLLER
✓ MISSION DAY
✓ PARTS FAILURE?
✓ CREW ILLNESS?
✓ METEOROID PUNT'R.
SCHEDULING
✓ TIME SPENT IN SPEC. ATTITUDES
STATION INVENTORY
• IDENTIFY LAUNCH TIMES
• GENERATE "NUMBER OF CREW ABOARD" PROFILE
• UPDATE INVENTORY LEVELS
• ADJUST FOR PARTS FAILURE, CREW ILLN'S., METER'D. PUNCTURE
• COMPUTE OPTIMIZED ORDER AMOUNTS
• COMPUTE MAX. STAY-TIME
• CALCULATE MAX. SPECIAL-ATTITUDE TIME
PLANNING MODE
COMPLETE MISSION PROFILE:
✓ INVENTORY LEVELS
H_2O
LB
TIME
✓ MAXIMUM STAY-TIME
LAUNCH #1
DAYS OF SUPPLY
CRIT
TIME
SIMULATION MODE
CURRENT INVENTORY STATUS
✓ INVENTORY LEVELS
CAT.
LEVEL
ORDER
✓ MAXIMUM STAY-TIME
DAYS OF SUPPLY
CRIT.
TIME

Figure 10-2

However, several categories require special computational procedures. Waste collection spheres, charcoal filter canisters, and subsystem components requiring periodic replacement (CMG bearings, door seals, etc.) must be treated as units having usage intervals. The categories of expendables used and their usage-rate relationships (or replacement intervals and weights) are given in Table 10-1.

Table 10-1

USAGE RELATIONSHIPS FOR EXPENDABLES

Expendable	Usage Relationship
H_2O for atmospheric resupply	Rate = .727 kg/day + (.745 kg/man-day) x crew size = 1.60 lb/day + (1.64 lb/man-day) x crew size
N_2 for atmospheric resupply	Rate = 0.564 kg/day = 1.24 lb/day
Emergency repressurization O_2, and PLSS resupply	Rate = (0.0118 kg/man-day) x crew size = (0.0259 lb/man-day) x crew size
Fuel	(See discussion in text)
Miscellaneous wick, complexing agent, urine bags, laundry supplies, and clothes	Rate = (0.129 kg/man-day) x crew size = (0.284 lb/man-day) x crew size
Waste spheres	Replacement Interval = 180 man-days Replacement Weight = 4.45 kg = 9.80 lb
Charcoal filter canisters	Replacement Interval = 90 days Replacement Weight = 6.77 kg = 14.9 lb
Food	Rate = (0.850 kg/man-day) x crew size = (1.87 lb/man-day) x crew size
Spares for components replaced periodically	Rate = 5.9 kg every 90 days 13 lb every 90 days 18.2 kg every 180 days 40 lb every 180 days 892 kg every 360 days 1962 lb every 360 days
Spares for components replaced at failure	Rate (expected) = 2.16 kg/day = 4.76 lb/day

10.2.2 Calculations of Consumption Rates

10.2.2.1 H_2O, N_2, O_2, Miscellaneous, and Food Calculations - Calculations of the consumption rate constants given in Table 10-1 are presented below. The rates are computed by an equation of the form $R_i = A_i + B_i \times cs$, where cs is crew size.

1. (H_2O):

   Total use rate of O_2 for a six-man crew is 5.88 kg/day; each man consumes O_2 at the rate of 0.87 kg/day, thus, six men consume

   $$6 \times 0.87 = 5.22 \text{ kg/day;}$$

   therefore, the leakage loss is

   $$5.88 - 5.23 = 0.65 \text{ kg/day.}$$

   This requires

   $$9/8 \times 0.65 = 0.73 \text{ kg/day } H_2O;$$

   thus,

   $$A_1 = 0.73 \text{ kg/day}$$
   $$= 1.60 \text{ lb/day.}$$

   Six men produce 1.43 kg/day excess metabolic water; hence, each man produces

   $$1.43/6 = .238 \text{ kg/day.}$$

   Each man requires

   $$0.87 \times 9/8 = 0.98 \text{ kg/day;}$$

hence, the amount to be resupplied is

$$0.98 - .238 = 0.74 \text{ kg/man-day};$$

thus,

$$B_1 = 0.74 \text{ kg/man-day}$$
$$= 1.64 \text{ lb/man-day}.$$

2. (N_2):

No nitrogen is consumed by the crew, hence

$$A_2 = 0.56 \text{ kg/day} = 1.24 \text{ lb/day}$$

$$B_2 = 0 \text{ kg/man-day}.$$

3. (PLSS 0_2):

The only available data for computing rates consisted of

Basic Resupply--six men, 90 days = 6.36 kg

It was assumed that amount of EVA activity was dependent on crew size, hence

$$B_3 = 6.36 \text{ kg}/6 \text{ men} \times 90 \text{ days} = .0118 \text{ kg/man-day};$$

thus

$$A_3 = 0 \text{ kg/day}$$

$$B_3 = .0118 \text{ kg/man-day} = .0259 \text{ lb/man-day}$$

It should be noted that category 3 includes emergency resupply oxygen; hence, the assumption that if the PLSS supply is exhausted, emergency 0_2 will be used to resupply the PLSS is inherent in the subroutine. This seems a reasonable assumption, since the emergency O_2 supply of 47.7 kg would last 674 days as PLSS supply for a six-man crew. Conversely, using the emergency O_2 as PLSS supply for 57 days (the maximum stay-time beyond the 90-day period for which the regular PLSS supply lasts) would reduce emergency O_2 by less than 10%.

4. Miscellaneous:

The miscellaneous category includes

urine bags	40.3 kg	6 men, 90-day resupply
complexing agent . . .	7.3 kg	
wick	9.2 kg	
Total	56.9 kg	

or

.105 kg/man-day

= 0.232 lb/man-day.

Also included are

laundry supplies . . .	0.041 kg/day	(6 men)
clothes	0.100 kg/day	
	0.141 kg/day	

or

0.0235 kg/man-day

= 0.0517 lb/man-day

Since all items are crew-related,

$A_5 = 0$ kg/day

$B_5 = 0.129$ kg/man-day

$= 0.284$ lb/man-day

5. Food:

Food consumption rate is 5.05 kg/day for six men; hence,

$A_8 = 0$ kg/day

$B_8 = 0.84$ kg/man-day

$= 1.85$ lb/man-day

10.2.2.2 Fuel Consumption Calculation - Calculation of fuel consumption rates is complicated by dependency upon altitude, station orientation, and calendar year (solar flux-induced variations in atmospheric density). A relationship was devised which approximates dependency on altitude, using orientation and calendar year-keyed constants. It was assumed that the station is operating in configuration X, altitude between 140-225 nautical miles, during the 1969-1975 time period, with the Brayton Cycle isotope power system.

In determining the attitude control propellant requirements, the largest portion of the gravity gradient propellant (85 to 95 percent) is independent of year and is essentially independent of altitude. (For a change from 200 to 160 n.mi., the resulting percent increase in fuel requirements is 4×10^{-11}%.) If a constant amount is assumed for each year, some error is introduced. A spot check indicated the error to be about 10 percent (1972). More variation should be expected before 1972, and less after 1972. If the data were available for each year, the consumption rate could be linearly approximated. In the 1972 case, this would reduce error to 2½ percent. If drag coefficients were available for configuration X, these approximations might be improved by using average density profiles. Linear interpolation between years will result in a maximum error of 2 percent in the inertial mode and less than 0.5 percent in the belly-down mode. The inertial mode error can be reduced to less than 0.5 percent by ½-year interpolation; however, this procedure was not deemed necessary. It should be noted that all data were read from graphs, thus introducing a small amount of error. In addition, the information contained in graphs is slightly inaccurate, since in many cases, divisions assigned equal value were actually not equal in size.

Many of the problems encountered in attitude control propellant requirements calculations also exist in calculating orbit-keeping propellant requirements. In addition, altitude dependence is very pronounced, especially in the 1969-1972 and 1977-1980 time periods. Had the data been available, a desirable approach would have been ½-year- and 10-mile-interval interpolation from a matrix of values. However, the necessary information was available only for the years

1969, 1971, and 1972; and only for the belly-down mode. Only the 1972 information was in the desired configuration. An alternative procedure was actually utilized; an exponential fit was attempted on each of the available curves, with the hope that a common property would be found. An exceptional semilog fit was obtained in the 155-195 range. A slight amount of disparity (10 percent) occurred at 200 n.mi.; however, all three plots had the same slope. Two were plotted for the MORL solar panel and the third for the Isotope Brayton power system. Since the primary difference in the orbit-keeping propellant requirements is aerodynamic drag, it was concluded that the relationship indicated by these three years could be extended to all years in both belly-down and inertial mode with the Isotope Brayton system. This assumption obviously introduces some error; furthermore, the data necessary to determine the exact amount of error present are not available.

The means of approximation is to

1. Interpolate requirements at 200 n.mi. (This information is available for each year in each configuration. Less than 10 percent error can be reduced to less than 2 percent by ½-year interpolation.)
2. Determine which of the family of curves is desirable for use. (Additional error is introduced at this point,

since the exponential fit was not as suitable at 200 n.mi. as at lower altitudes; data are not available to reduce this error.)

3. Compute consumption for the given altitude. The relationship is:

$$R_i = \mathrm{alog}_{10}\ [-\ .022 \mathrm{xAL} + E_i\ ]\ /30 \quad (i = 1,2)$$

where

E_i is the result of the interpolation in step 1;

AL is the altitude

and the result is divided by 30 to obtain lb/day from lb/month.

The orbit-keeping requirement for inertial orientation will be accomplished while in the belly-down orientation. The total requirements in the belly-down mode will be determined by the dominating requirements: (1) attitude control or (2) belly-down orbit-keeping + inertial orbit-keeping. The consumption rate is then

$$\text{rate} = R_1 \times PB + R_2 \times PI$$

where

R_i is determined in step 3 above;

PB is fraction of time in belly-down mode

PI is fraction of time in inertial mode.

Thus, with a matrix of constants containing a value for each year and each orientation, the fuel consumption rate under given conditions may be approximated. Because of a lack of data, the values in the supplied library restrict the operational period to the 1969 to 1975 era. Also because of insufficient data, there is a restriction on the orbital altitude which may be considered; the altitude must be less than 417 km (225 n.mi.) and greater than 260 km (140 n.mi.). These constraints, of course, may be readily removed when data become available.

In determining the logistics requirements, the station is filled to capacity, providing the load does not exceed the logistics payload weight constraint. Otherwise, the order amounts are optimized with respect to maximum possible stay-time, i.e., the time until a logistics launch is mandatory. The optimization is subject to such priority items as spares, waste collection spheres, and charcoal filter canisters. The concept of optimization is to plan so that every category of expendables is exhausted at the same time. Since a change in crew size will change the optimum distributions, first consideration is given to the crew on board in the imminent launch period. However, if a station constraint (e.g., fuel) proves the controlling factor, the remaining logistics capacity can be used to increase the stay-time of the crew on board in the next launch period, using the same procedure.

10.2.3 Other Computations Performed by the Inventory Section

Two other computations are made by the inventory section, (1) maximum possible stay-time and (2) maximum special attitude time. A special routine is used to calculate the maximum stay-time only if optimization of order amounts is unnecessary, since this calculation is an integral part of the basic optimization procedure. Special attitude time is the maximum time which may be spent in non-belly-down orientation without exhausting the fuel supply. It is used as a resource by scheduling, and its calculation is based on the current fuel consumption rates.

10.2.4 Operation in the Simulation Mode

The operation of the inventory section in the Simulation Mode differs only slightly from that of the Planning Mode, and almost all subroutines are interchangeable. Due to the method of operation of the Space Station Model in the Simulation Mode, expendables requirements are generated just prior to the simulated time of each launch. The quantity of spares needed is known; hence, actual usage amounts, rather than expected values, occur in the calculation of inventory level in category 10 (spares replaced at failure).

Allowance is made for failure (at a reduced rate) of those parts which are periodically replaced. The order amount optimization procedure differs from that of the Planning Mode in that only one optimization is performed, since the length of the next launch period is unknown at the time of ordering.

The occurrence of meteoroid punctures is also simulated by the model. It is assumed that all punctures are of the same size (½-inch diameter hole) and require the same time (20 minutes) to detect, locate, and repair. Calculation is made of the amount of atmosphere lost, and the inventory levels are adjusted to reflect this loss. If the loss drops an inventory level below the critical supply level, an abort is called.

10.3 Contingency Analysis Section

The contingency analysis section processes each failure at its simulated time of occurrence. This process includes a check for alternate modes of operation, classification of failure, computation of resources lost, and a repair analysis. After determining alternate modes of operation and corresponding allowable downtimes, a failure is classified according to its criticality. A flow network analysis technique is used to compute subsystem resources available following a failure. A repair analysis is performed to define the repair task, to determine spares availability, and to initiate scheduling of the repair task.

10.3.1 Component Categorization

Each of the seven laboratory subsystems is broken down into categories or types of components; and each component within a category is identified by the same set of descriptors, i.e., failure rate, repair time, etc. This method of combination saves storage space and run time. The failure of each individual component is simulated, so that at any time it is known exactly which components are in the failed status. The library contains data for each category which describe the component breakdown within the given category (e.g., number of components of this type, number of redundant components, etc.).

10.3.2 Alternate Modes of Operation

Using the library data and the status of each component in the given category, it may be determined if sufficient unfailed components remain in that category to perform the desired function. If not, an alternate mode of operation is sought. If an alternate mode is available, the following are specified as category descriptors: (1) the categories of components involved in the alternate mode and (2) the length of time which may safely be spent operating in the alternate mode. Also included is the "no-alternate" safe time (safe time if the alternate mode, due to other failures, is not operational or if no alternate mode is provided). From this information, the safe time may be computed for any component under any set of circumstances.

10.3.3 Failure Classification

From the safe time, it is possible to classify the failure according to criticality in one of the following classifications:

1. Degradation and Experimental Return - At worst, some loss of experimental data return occurs, or operation in a back-up mode is necessary; spares, if not on board, are resupplied on the next launch.
2. Critical - If unspared, an immediate logistics launch is necessary to prevent mission failure.
3. Supercritical - If unspared, mission failure is inevitable (there is not time for a special launch).

If the station can operate indefinitely in the present status (in particular, safe time $> 10^5$ hours), this is considered a degradation/experimental return failure. If operation (without jeopardizing crew safety or mission success) is limited, but to a time greater than that necessary to receive spares on a special launch (safe time > 120 hours - nominal time for a special launch), the failure is considered critical. If safe time is less than the amount of time required to receive spares on a special launch, this is classified as a supercritical failure.

10.3.4 Spares Inventory

Classification is essential in processing a failure, since each of the failure classes will initiate distinct lines of action, depending upon the existence (or nonexistence) of a spare on board. The spares inventory is maintained by component category, and is updated after each use of a spare. Hence, when a failure occurs, it is known if a spare of that type is on board.

10.3.5 Processing a Failure

For degradation failures, the existence (or nonexistence) of a spare determines whether the repair will be performed immediately or after the arrival of the next logistics launch. Although an individual failure of this type cannot dictate a special launch, it is possible that multiple degradation failures could drop station operating efficiency sufficiently to warrant a launch (see Subsection 10.4). If a critical failure occurs and the necessary spare is not on board, a special launch is requested immediately for shipment of the spare (see Subsection 10.4.2). Other spares which are needed to replenish the initial spares package are also shipped. However, in the case of an additional launch (as opposed to a launch whose date has been moved up), no provision is made to include expendables.

In addition, a check is initiated to ensure that the spare arrives and the component is repaired within the safe time. If it is not, abort procedures will be initiated. Each of the seven subsystems is described by abort statements stating which components must be operable to avoid abort conditions. In addition, these statements are used, in the calculation of efficiency, to compute the probability of an abort. In the case of an unspared supercritical failure, the abort statements are checked to ensure that an abort is necessary; as a safety measure, this procedure is also followed in the case of an unspared degradation failure.

For any spared failure, the random events generator uses category-related library data, i.e., optimistic, mean, and pessimistic repair times, to determine a random repair time from a log-normal distribution. In special cases, a fixed repair time (or failure time) may be specified by using a deterministic distribution (see Subsection 10.5). The repair task is set up to be scheduled using the skills required and the random repair time. The task requires one to three men, depending on expected duration (mean repair time). In order to facilitate scheduling, it is desirable to allocate less than two hours of work per man for a particular repair. However, for tasks which take longer than six hours to accomplish, scheduling in this manner may be impractical.

10.3.6 System Resources

Available system resources may be computed for any of the seven laboratory subsystems by using a flow-network technique; however, because of computer storage limitations, only the power system is currently being processed in this manner. This method, known as the Ford-Fulkerson theory, utilizes a network to represent each subsystem. The arcs of the network represent system components, and each arc is assigned capacities corresponding to the component capabilities. The nodes represent points of component interface. A "cut" is a partitioning of the set of nodes into two sets, placing the beginning node and the ending node in diffent sets. The "cut capacity" for a given cut is the sum of the capacities of all the arcs which have one node in one set and the other node in the remaining set. By applying a theorem (somewhat analogous to the duality theorem in linear programming), the minimum, overall possible cuts of the cut capacities is found to be equal to the maximum possible flow through the network. Thus maximum power levels are calculated internally following failures in the system. This procedure is described in Figure 10-3. An algorithm is used to generate the cuts; this consists of a binary number generator, with each node corresponding to a place (position) in the binary number. Thus, each node is assigned to the beginning or ending set of the partition according to the occurrence of a 0 or 1 in the place to which it corresponds. Faster methods of solving the network are available, but each requires considerably more logic than the overall speed increase would warrant.

For each subsystem, the option of whether or not to compute available resources is carried in the library. The supplied library computes resources only in the power subsystem, although resources in the communications and data management subsystem are

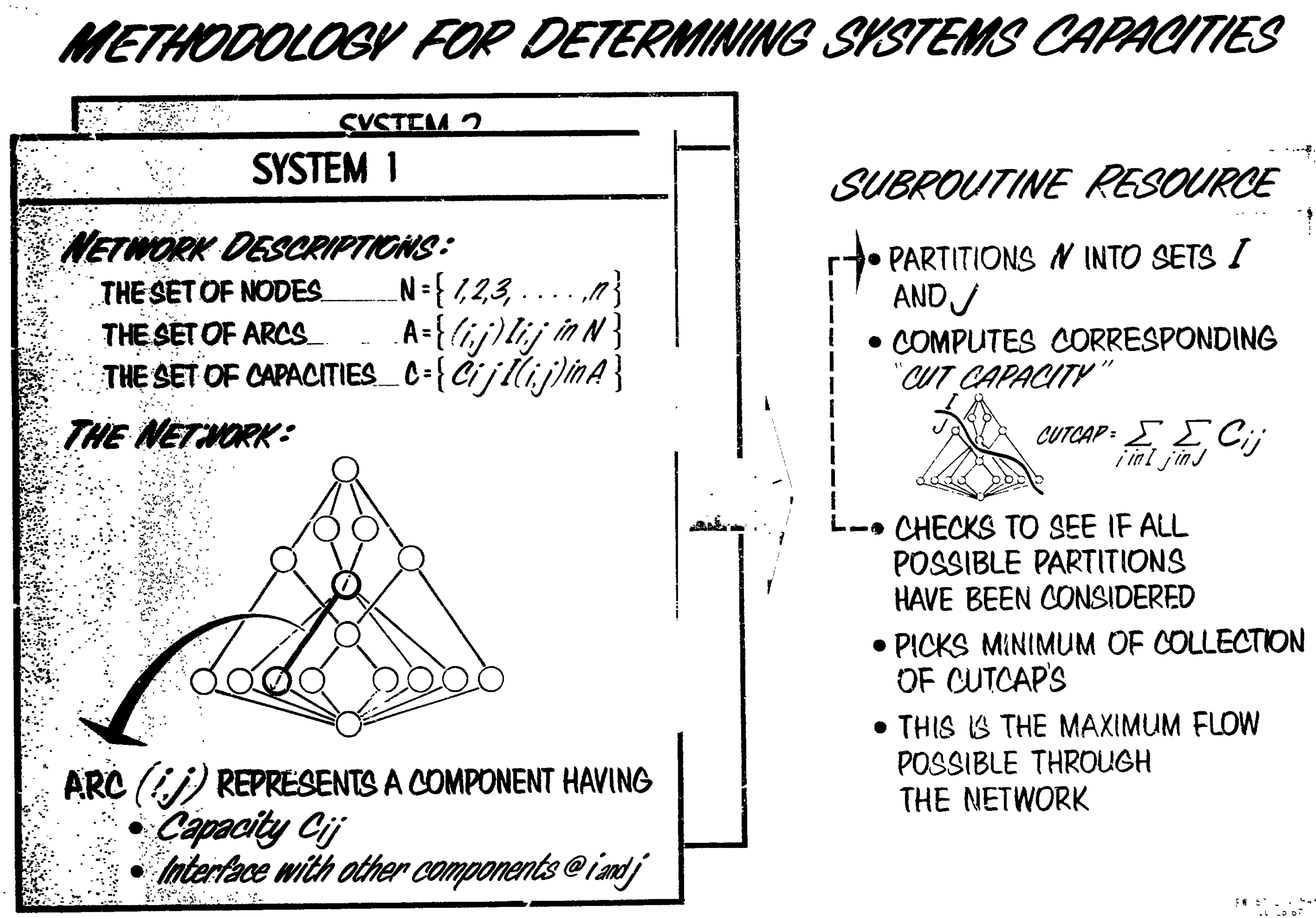

METHODOLOGY FOR DETERMINING SYSTEMS CAPACITIES
SYSTEM 2
SYSTEM 1
NETWORK DESCRIPTIONS:
THE SET OF NODES ____ N = { 1,2,3, ... ,n }
THE SET OF ARCS ____ A = { (i,j) I i,j in N }
THE SET OF CAPACITIES ____ C = { Cij I (i,j) in A }
THE NETWORK:
i
j
ARC (i,j) REPRESENTS A COMPONENT HAVING
• Capacity Cij
• Interface with other components @ i and j
SUBROUTINE RESOURCE
• PARTITIONS N INTO SETS I AND J
• COMPUTES CORRESPONDING "CUT CAPACITY"
I
J
CUTCAP = $\sum_{i \text{ in } I} \sum_{j \text{ in } J} C_{ij}$
• CHECKS TO SEE IF ALL POSSIBLE PARTITIONS HAVE BEEN CONSIDERED
• PICKS MINIMUM OF COLLECTION OF CUTCAP'S
• THIS IS THE MAXIMUM FLOW POSSIBLE THROUGH THE NETWORK

Figure 10-3

also checked. After the new system resources are obtained, the process of rescheduling is initiated as a result of the change in resource level; a check on station operating efficiency is also begun.

10.3.7 Other Considerations

If the spared failure is in the supercritical class, one further computation is made. This computation determines if the spares level in this category has fallen low enough to jeopardize mission success. Using a Poisson distribution, a calculation is made to determine the probability of having more failures than available spares in the next 120 hours (nominal emergency resupply time). If the probability is greater than 0.1, an immediate resupply is requested. This means that 10 percent of the expected incidence of critical spares exhaustion would fail to be recognized in time to avoid an abort.

At the (simulated) time of a repair completion, the contingency analysis section changes the component's status from failed to repaired, checks for reclassification of any other failures in the same subsystem, and, if indicated, recomputes the available subsystem resources.

10.4 Station Efficiency Section

The station efficiency section provides a simple check of operating efficiency based on probability of mission success, probability of crew survival, and percent of experimental return (see Figure 10-4). This measure of efficiency is used as a decision tool for calling special logistics launches. It is possible that enough noncritical failures could occur which would drastically reduce experimental return or even jeopardize mission success and crew safety. Therefore, although special shots may be dictated, because of specific critical or supercritical failures, it is also desirable to have the capability to request special shots as a result of multiple noncritical failures.

10.4.1 The Efficiency Measure

After each contingency an efficiency measure is calculated, based on the following factors. The probability of mission success is computed by calculating, for each subsystem, the probability of an abort occurring before the next scheduled launch due to the particular subsystem. For this calculation, the abort statements (stating which components must be operable to avoid abort conditions) are used in conjunction with failure rates and probability of unsuccessful repair. The probabilities that no abort will occur are combined to yield the probability of mission success. The

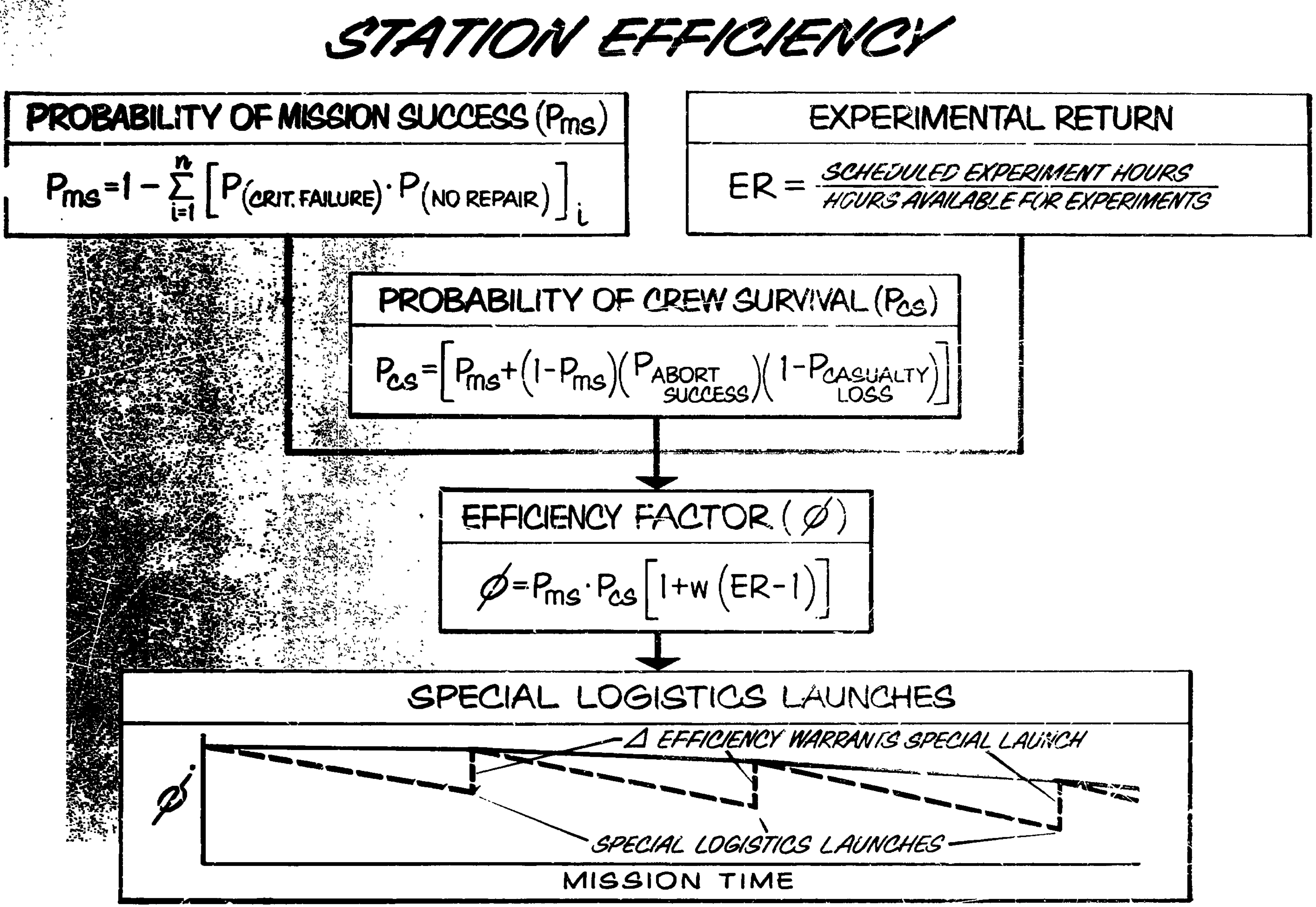

STATION EFFICIENCY
PROBABILITY OF MISSION SUCCESS (P_{ms})
$P_{ms} = 1 - \sum_{i=1}^{n} \left[P_{(CRIT. FAILURE)} \cdot P_{(NO\ REPAIR)} \right]_i$
EXPERIMENTAL RETURN
$ER = \frac{\text{SCHEDULED EXPERIMENT HOURS}}{\text{HOURS AVAILABLE FOR EXPERIMENTS}}$
PROBABILITY OF CREW SURVIVAL (P_{cs})
$P_{cs} = \left[P_{ms} + (1 - P_{ms}) \left(P_{\substack{ABORT \\ SUCCESS}} \right) \left(1 - P_{\substack{CASUALTY \\ LOSS}} \right) \right]$
EFFICIENCY FACTOR (ϕ)
$\phi = P_{ms} \cdot P_{cs} \left[1 + w (ER - 1) \right]$
SPECIAL LOGISTICS LAUNCHES
Δ EFFICIENCY WARRANTS SPECIAL LAUNCH
ϕ
SPECIAL LOGISTICS LAUNCHES
MISSION TIME

Figure 10-4

probability of crew survival is calculated from (1) the probability of mission success, (2) the probability of a successful abort if the mission fails, and (3) the probability of casualty due to other circumstances (illness, EVA accidents, etc.). The latter two probabilities are included in the model input. The percent of experimental return is defined as the number of scheduled experimental man-hours divided by the total number of man-hours available. After each contingency-caused rescheduling, the number of scheduled experiment hours is updated and used in the ensuing efficiency-level calculation.

The combination of these factors into an efficiency measure is based on the philosophy set forth in the MORL Phase IIB studies. Both safety and mission success are given the highest possible weighting factors of 1.0, while the weighting factor for the experimental program may be input. If no value is input, the value is assumed to be 0.0625 (1/16). The efficiency measure is computed by:

$$\text{Efficiency} = P\ (\text{mission success}) \times P\ (\text{crew survival}) \times [(1.0 + \text{WTC} \times (\text{Percent Experiment Return} - 1.0)]$$

where

WTC is the weighting factor for experiment return.

10.4.2 Estimating the Effect of a Special Launch

The efficiency which may be realized if a special launch is called may be estimated by (1) temporarily restoring all components to the operable status and (2) using for percent of experimental return the value of this measure at the beginning of the launch period (immediately after initial scheduling for the period, and before any contingency events). If a difference in these two values--the present efficiency and the efficiency after a special launch--is larger than an input cutoff value, a special launch is set up. Hence, a series of noncritical failures, if extensive enough, may dictate a special logistics launch.

10.5 Systems Library Data

A large portion of the station operations analysis task has consisted of gathering systems library data. As illustrated in Figure 10-5, each of the following seven laboratory subsystems was analyzed:

1. Environmental Control and Life Support
2. Electrical Power
3. Stabilization and Control
4. Reaction Control
5. Communications and Data Management

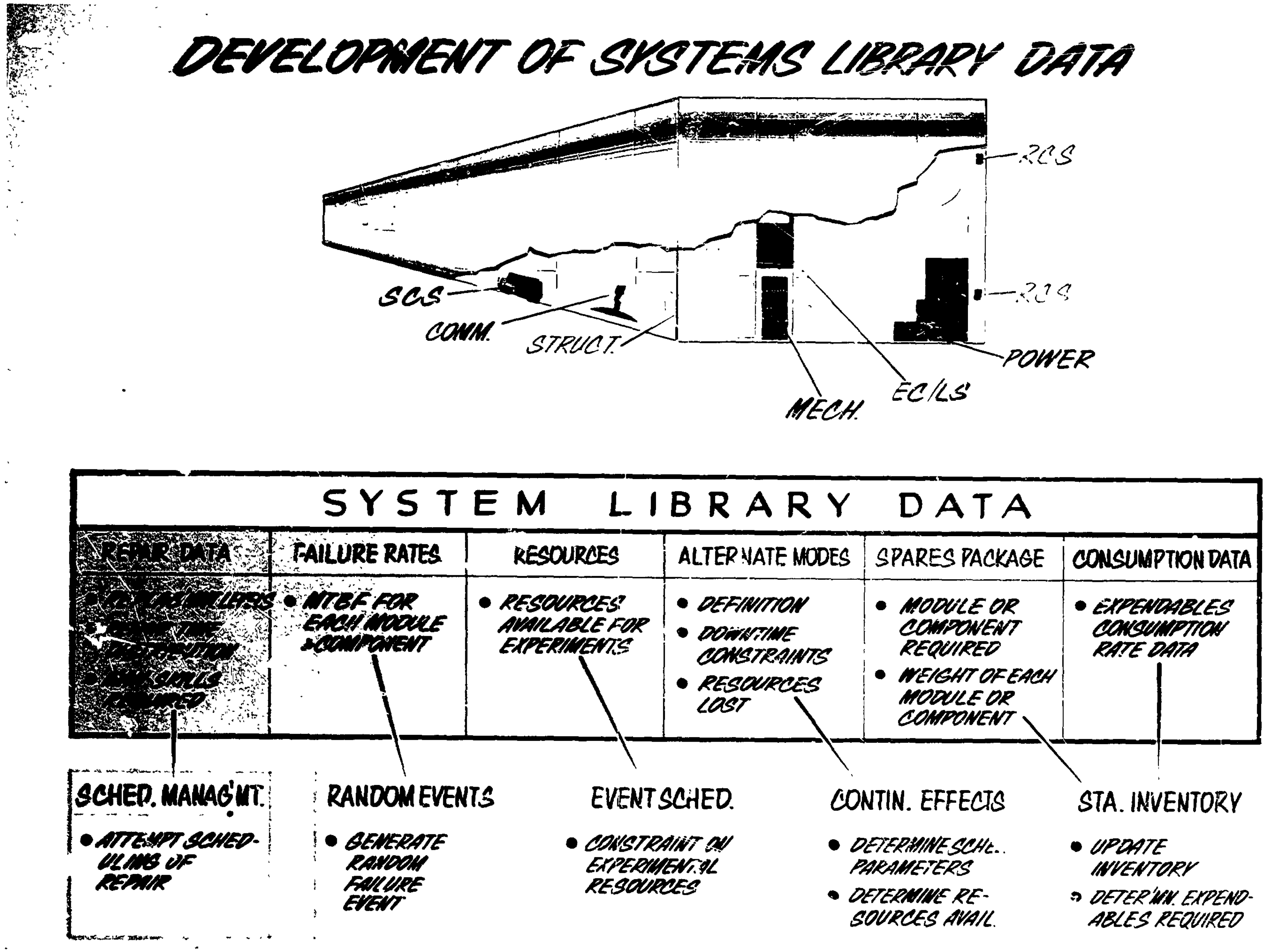

DEVELOPMENT OF SYSTEMS LIBRARY DATA
RCS
SCS
COMM.
STRUCT.
MECH.
EC/LS
POWER
RCS
SYSTEM LIBRARY DATA
REPAIR DATA
FAILURE RATES
• MTBF FOR EACH MODULE & COMPONENT
RESOURCES
• RESOURCES AVAILABLE FOR EXPERIMENTS
ALTERNATE MODES
• DEFINITION
• DOWNTIME CONSTRAINTS
• RESOURCES LOST
SPARES PACKAGE
• MODULE OR COMPONENT REQUIRED
• WEIGHT OF EACH MODULE OR COMPONENT
CONSUMPTION DATA
• EXPENDABLES CONSUMPTION RATE DATA
SCHED. MANAG'MT.
• ATTEMPT SCHEDULING OF REPAIR
RANDOM EVENTS
• GENERATE RANDOM FAILURE EVENT
EVENT SCHED.
• CONSTRAINT ON EXPERIMENTAL RESOURCES
CONTIN. EFFECTS
• DETERMINE SCHE. PARAMETERS
• DETERMINE RESOURCES AVAIL.
STA. INVENTORY
• UPDATE INVENTORY
• DETERMIN. EXPENDABLES REQUIRED

Figure 10-5

6. Mechanical Systems (centrifuge, radial storage, etc.)

7. Structure.

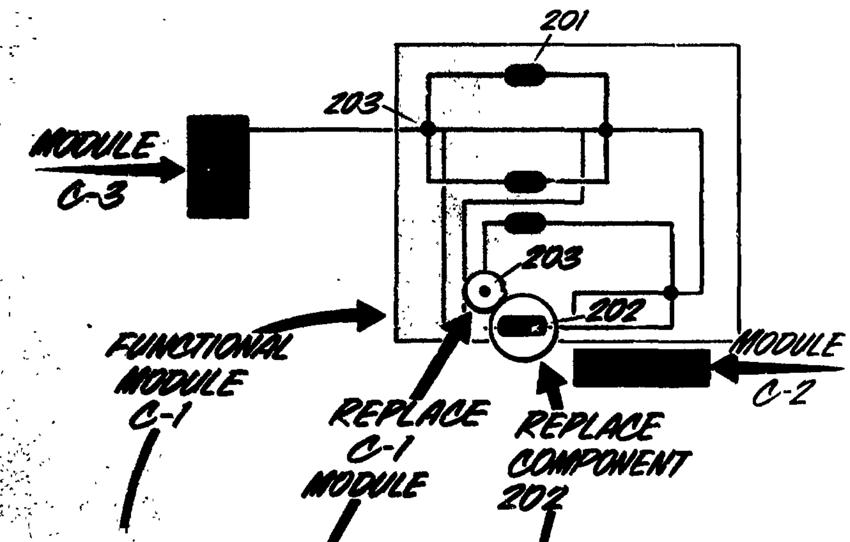
The analysis consisted of determining replacement levels, failure rates, resource availability data, repair task data, etc. These data are used in the contingency analysis section, efficiency section, and in other areas of the model for determination of failure times, analysis of failures, and generation of repair tasks.

10.5.1 Data Sources

When possible, data were obtained from MORL IIB system descriptions and specifications. Where data voids existed, earlier phases of the MORL study were used and were supplemented from other sources. For example, the Convair Division of General Dynamics assisted in determining the Environmental Control and Life Support System (EC/LS) replacement levels, failure rates, repair times, etc. The EC/LS contains a large number of components, some of which are not readily replaceable. An analysis of replacement levels in the system was performed to determine a maintenance level on which to base the policies concerning spares, replacement times, and alternate operational modes. Mean-time-between-failures values (MTBF's) were estimated for each maintenance level selected. This is illustrated in Figure 10-6; Module C-1 has an estimated MTBF of 23,000 hours, excluding components which are replaceable at the component level (e.g., silica gel canisters).

EXAMPLE OF SYSTEM'S LIBRARY DATA ANALYSIS & TABULATION EC/LS

ATMOSPHERIC PURIFICATION SUBSYSTEM - GROUP C-CO_2 SEPARATOR



- 15 GROUPS IDENTIFIED
- SUBDIVIDED INTO 35 REPLACEABLE MODULES
  - C-1
  - C-2
  - C-3
  - ETC.
- DELINEATED REPLACEABLE COMPONENTS/MODULES
- TABULATED DATA SHOWN FOR EACH REPLACEMENT LEVEL

MODULE	NO. REQD.	LOCAT	COMPONENT IDENT. NO.	COMPONENT IDENT. NAME	NO./MODULE	EXPENDABLE / REPLACEABLE MAINTENANCE CODE	EXPENDABLE / REPLACEABLE REPLACEMENT INTERVAL	MTBF HRS. x10^-3	REPLAC'MT TIME OPTIMISTIC	REPLAC'MT TIME EXSPECTED	REPLAC'MT TIME PESSIMISTIC	Crew Types Qualified to make Replacement 1	2	3	4	5	6	WT. & VOL.
C-1	2							22	5HR EACH	10HR	20HR	X	A	A		A		80LB 9FT³
			201	CANISTER SILICA GEL		R	AT FAILURE	330	5HR. EACH	8HR	10HR	X	X	X		X		10LB 1FT³
			202	CANISTER ZEOLITE		R	AT FAILURE	330	5HR EACH	8HR	10HR	X	X	X		X		10LB 1FT³
			207	TIMER		R	AT FAILURE	83	1HR	2HR	5HR	X	X	X		X		2LB 0.1FT³
			203	VALVE [illegible]		M												

Figure 10-6

10.5.2 Repair Task Descriptors

Selection of the skills required for a repair is dependent upon both the type of repair needed and the amount of time required to perform the repair. If the repair task requires replacement of a module, a specialist for this system is chosen, although he may also be assisted by a crewman who has had general training in the task area. If the repair involves a component replacement, an electromechanical technician is chosen to carry out the repair task. In a few cases involving minor repairs, the repair task may be performed by anyone available. If practical, the task is assigned to one, two or three crewmen, depending upon the following:

If repair time $\leq$ 2 hours, one man is assigned

If 2 hours $<$ repair time $\leq$ 4 hours, two men are assigned

If 4 hours $<$ repair time, three men are assigned.

However, these library data may be changed, if desirable.

The actual repair time used for scheduling is a random number drawn from a log-normal distribution determined by:

1. Optimistic repair time - an optimistic estimate of the time required for repair. (In particular, this is the 0.05 point on the distribution curve; 5 percent of the area under the curve lies to the left of this point.)
2. Mean repair time - the mean of all repairs of this type.

3. Pessimistic repair time - a pessimistic estimate of the required time (0.95 point on the curve).

These variables also must satisfy the following restrictions: (1) they all must be positive, and (2) the difference between pessimistic and mean repair times must be greater than the difference between mean and optimistic repair times.

Although the log-normal distribution is specified for all repair tasks in the supplied library, any one of the eight distribution types accepted by the random events generator may be specified. The usage of these distributions is elaborated upon in Section 11.0. These distribution types include:

1. uniform
2. exponential
3. Poisson
4. normal
5. log-normal
6. Weibull
7. binomial
8. deterministic.

Failure times are determined in the same manner as the repair tasks. For instance, by using a deterministic type, components may be forced to fail at a specified time.

10.5.3 Alternate Mode Descriptors

Also included in the library is information describing alternate modes available for a failed component. The set of components has been divided into categories, each of which contains a number of identical components operating in parallel. If fewer than the necessary number of components remains unfailed, then the category is considered to be in the failed status. Both the number of components in the category, and the number needed are considered library data; both may have any non-negative value, subject to the condition that there be at least as many components in the category as the number needed. The components constituting the alternate mode are listed, along with (1) the time which may be safely spent in the alternate mode and (2) the safe time if the alternate mode is inoperable (or if there is no alternate mode available). If a component category number in this list is prefaced by a negative sign, that component category alone is sufficient to render the alternate mode operable; if none are prefaced by negative signs, all component categories must be in the failed status to render the alternate mode inoperable.

10.5.4 Spares Package Descriptors

A description of the spares package is included for each component in the library. Each category is described according to the weight of one spare and the initial number of spares. The present supplied library includes a spares package which is restricted to 227 kg (500 lb). This restriction (227 kg) is based on an actual volume restriction of 1.4 m^3 (50 ft^3) and a 10:1 weight-to-volume ratio. It is anticipated that extensive exercising of the model will allow this package to be improved.

10.5.5 Other Libraries

Several other station operations libraries are used by the model. These include the inventory section's library, consisting of a series of usage constants, and a crew task library. These libraries are discussed in other sections of this report.

10.5.6 Crew Illness

Three types of crew illness (discussed in detail in Section 6.4) are simulated in the stations operations routine:

1. Minor illness - an illness which incapacitates the crewman for a period of 48 hours
2. Major illness - an illness which would endanger the life of the crewman if he were not returned to earth and hospitalized immediately
3. Contagious illness - a contagious disease which would endanger the lives of all the crew if the crew were not returned immediately to earth.

Each type of illness is handled differently. A crewman suffering from a minor illness is removed from the scheduling inventory by assigning him a dummy 48-hour task which occupies all his work time.

A crewman with a major illness is returned to earth immediately. Two other crewmen are selected to accompany him, as the Apollo module requires two able men to handle reentry procedures. In order to minimize disturbance of the crew rotation plan, these men are selected on the basis of the time remaining until their planned return to earth. A launch profile modification request is initiated to bring replacements for the returned crewmen (these replacements are assumed to be of the same skill types). Also scheduled are dummy tasks, which utilize all the crewmen's time until the replacements arrive.

If a contagious disease which would endanger the entire crew is contracted by a crewman, an abort is called for.

10.5.7 Aborts

If, for any reason, crew safety falls below a suitable level of acceptance, abort procedures are initiated. Several events which may cause an abort are:

1. A contagious disease
2. Failure to receive expendables resupply within allowable time

3. A parts failure, of the supercritical class, which is unspared
4. Failure to repair a critical failure in the allowable downtime (due possibly to a spare not arriving in time)
5. A series of failures rendering some critical function inoperable.

Events which may lead to an abort are discussed in detail in other sections of this report.

An abort situation terminates the problem. A simulation is made to determine if the abort is a success or failure, and the interval is evaluated.

11.0 SIMULATION OF PROBABILISTIC PHENOMENA

11.1 Introduction

The analysis of probabilistic phenomena and methods of simulating these phenomena consisted of three parts. Part one was directed toward the selection of a simulation technique for use in the Space Station Model. In part two the probabilistic phenomena to be considered were selected; and, in part three, a model routine was developed to perform the simulation operations.

11.2 Simulation Techniques

There are two basic methods, event-sequencing and time-slicing, for constructing a digital simulation model. In both methods, the set of all possible events and the set of all possible states of the system being simulated must be defined. In both methods, the state of the system changes if, and only, if, an event occurs.

In the time-slicing method, the computer is programmed to observe the system status at regular fixed intervals of time. Each interval must be observed whether or not an event (i.e., a change in the system status) occurs during that interval. Thus, in the time-slicing method considerable computer time can be spent observing the system in intervals of time in which there is no change in the system status.

In the event-sequencing method of simulation, the computer is programmed to proceed directly from one event to the next, ignoring those intervals of time in which there is no change in the system status. Because of its shorter computer run time and greater accuracy, the method of event-sequencing was selected for use in the Simulation Mode of the Space Station Model (see Figure 11-1).

11.3 Event Classifications

Events are defined as any phenomena which results in changes in the station status or station operations and are classified as either fixed or random.

The fixed events are those events whose time of occurrence can be expressed deterministically. All fixed event times are generated originally in the Planning Mode of the Space Station Model. However, rescheduling of these fixed events can occur in the Simulation Mode. For example, the date of the laboratory launch or any logistics launch will be a fixed event in the Planning Mode since the exact date may be computed deterministically. However, this date is subject to change in the Simulation Mode because of probabilistic considerations. In a like manner, the time for completion of station keeping tasks and experiments which are fixed events in the planning mode may be revised in the Simulation Mode.

Random events are those events whose time of occurrence cannot be expressed by a deterministic equation. These events are described by a probability density function which expresses the likelihood of the event occurrence as a function of some continuous

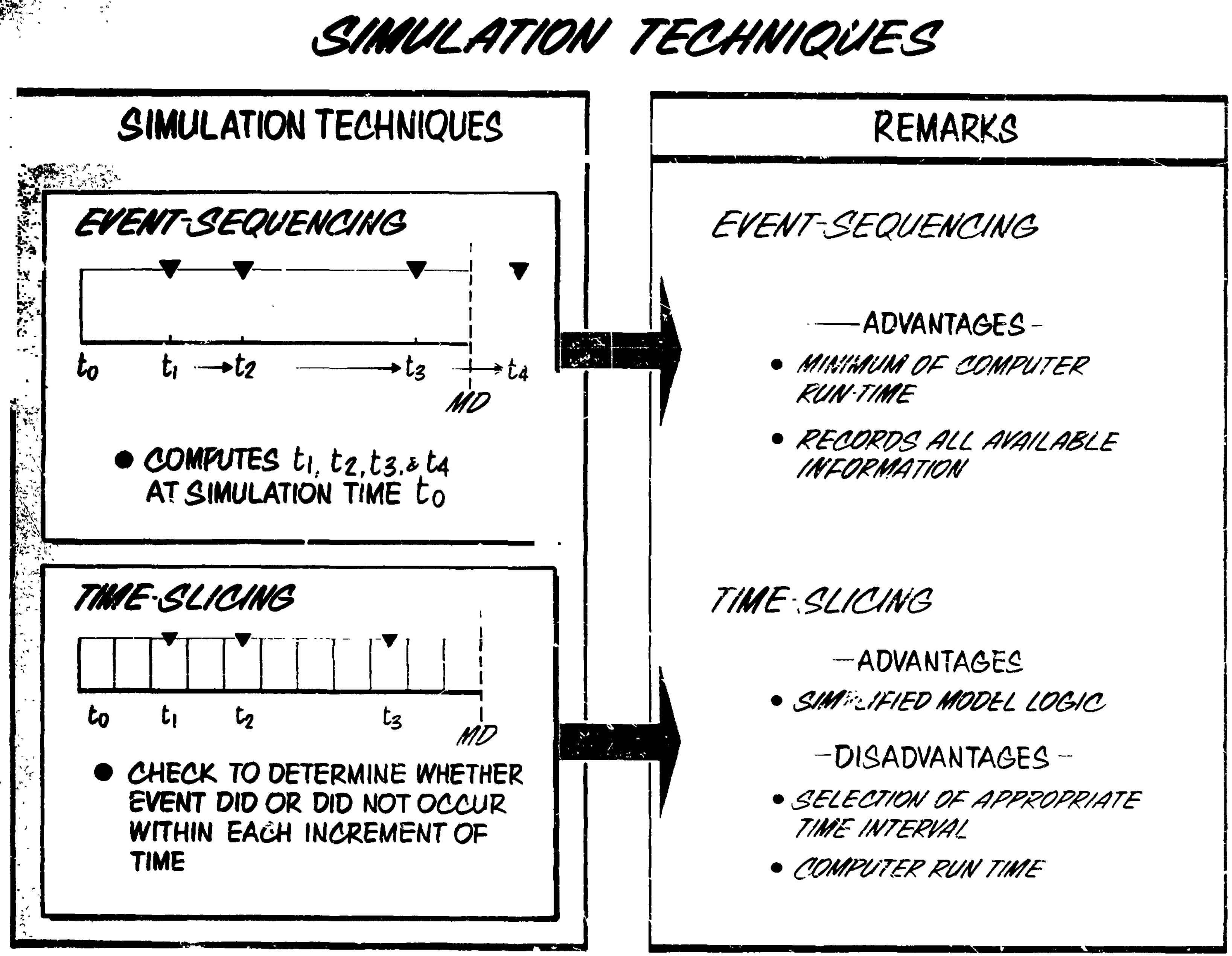

SIMULATION TECHNIQUES
SIMULATION TECHNIQUES
REMARKS
EVENT-SEQUENCING
t0 t1 t2 t3 t4
MD
COMPUTES t1, t2, t3, & t4 AT SIMULATION TIME t0
TIME-SLICING
t0 t1 t2 t3
MD
CHECK TO DETERMINE WHETHER EVENT DID OR DID NOT OCCUR WITHIN EACH INCREMENT OF TIME
EVENT-SEQUENCING
—ADVANTAGES—
MINIMUM OF COMPUTER RUN-TIME
RECORDS ALL AVAILABLE INFORMATION
TIME-SLICING
—ADVANTAGES
SIMPLIFIED MODEL LOGIC
—DISADVANTAGES—
SELECTION OF APPROPRIATE TIME INTERVAL
COMPUTER RUN TIME

Figure 11-1

variable such as time. Thus, random event occurrence is determined by a random observation from a probability density function.

The Simulation Mode of the Space Station Model is programmed to progress from one event to the next - observing event outcomes, determining their effects upon the space station, altering the station status as required, and maintaining a record of the event times, event outcomes, and station states. All events are mission-time sequenced and processed by the event controller. Only fixed events are considered in the Planning Mode of the Space Station Model. However, in the Simulation Mode, random events are also considered.

The random events to be considered have been divided into three categories as illustrated in Figure 11-2. Random events associated with the experimental program are the individual experiment durations, experiment failures, and, in special cases, such as the observance of random phenomena, experiment start times. Random events to be determined in the area of systems operations are (1) the points in mission time at which the system failures occur and (2) the systems maintenance task time requirements for each failure. Random events in the area of crew-related and special activities will include such things as (1) crew sickness, (2) meteoroid punctures, and (3) inactivity due to solar flare activity. If desired, special station keeping tasks can also be assigned variable duration requirements.

ORIGIN OF RANDOM EVENTS

CATEGORIES OF RANDOM EVENTS

- **EXPERIMENTS**
  - DURATION
  - FAILURES (Premature Termination)
- **SYSTEMS**
  - FAILURES
  - REPAIR TIME
- **CREW RELATED and SPECIAL ACTIVITIES**
  - CREW SICKNESS
  - STATION OPERATION TASK TIMES
  - SOLAR FLARES
  - METEOROID PUNCTURES

Figure 11-2

11.4 Random Event Generation Routine

The random event generation routine was developed to accomplish the simulation of random phenomena in the Space Station Model. This routine is used only in the Simulation Mode of the Space Station Model. The random event generation routine has two primary functions: (1) to determine the time of occurrence for all random events and (2) to determine the magnitude of the random event or its outcome, whichever is applicable. The random event generation routine consists of three separate subroutines as illustrated in Figure 11-3.

The first entry to the random event generation routine calls upon the subroutine REG(A) for determination of the time of first occurrence of each random event. The event occurrence times are then transferred to the event controller routine for processing. It is important to note that the random event times stored in the event controller are not used for planning purposes. That is, the random event occurrences and their effects upon the space station are not scheduled ahead of time and consequently are not processed until the simulation has progressed to the time of event occurrence. Thus, with respect to station simulation effects the random events occur in a completely unpredictive manner.

RANDOM EVENT GENERATION ROUTINE

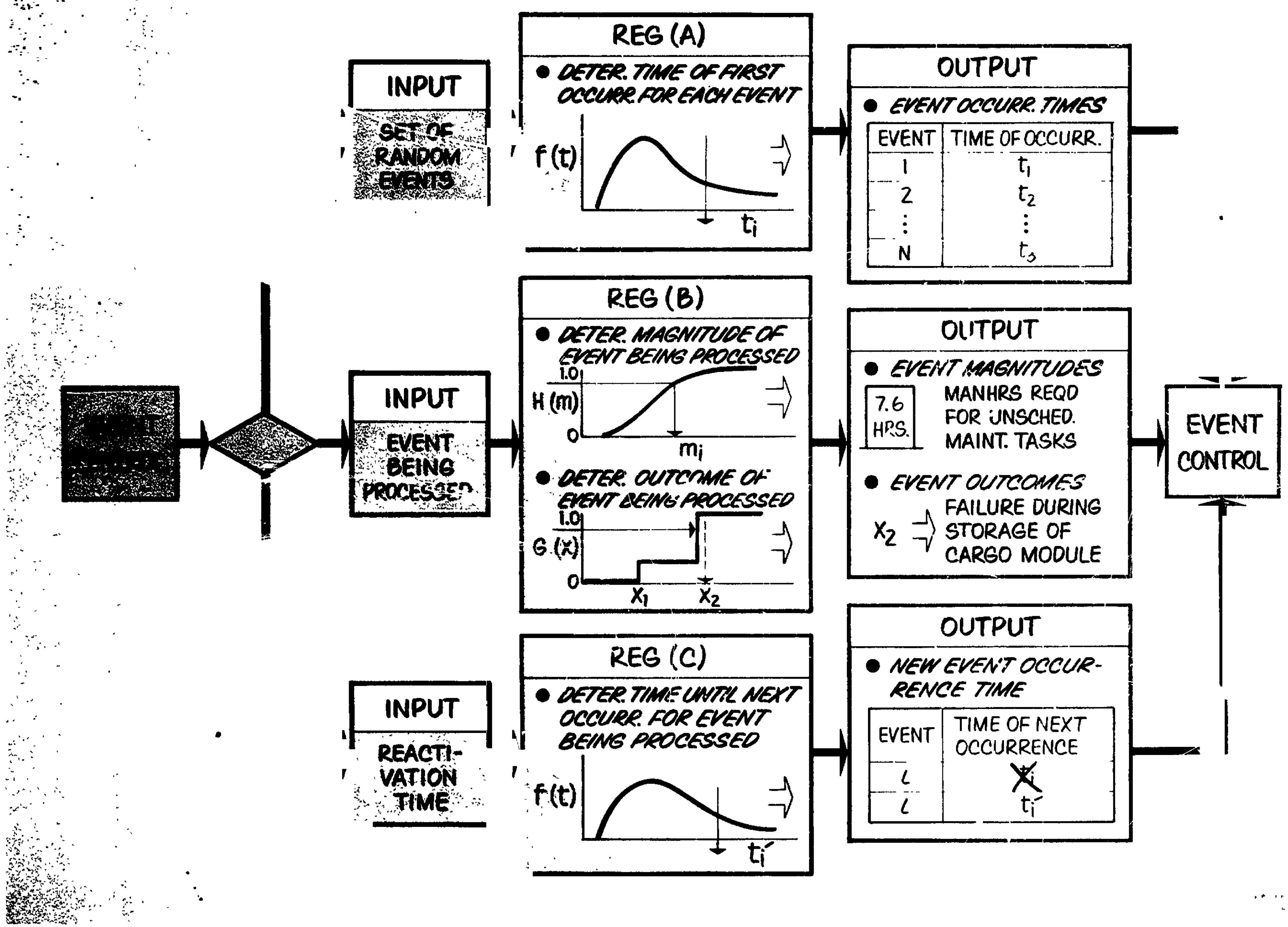


Figure 11-3

The second type of entry into the random event generation routine is made when the computer program progresses to the occurrence of a random event. The second subroutine, Reg (B), may respond in several ways. If this event is the completion of an experiment, the existing event time for that event is replaced with a date greater than the mission duration. This will prevent the event controller from selecting this particular event again. For any random event other than the completion of an experiment, the random event generator will determine the magnitude or outcome, whichever is applicable, of the event which has just occurred. For example, if the event is a system failure, the random event generator will determine the number of man-hours required to repair that failure. This man-hour requirement is transmitted to the station operations routine, where the system downtime is determined by integrating the man-hour requirement with other station considerations. The systems reactivation time will also constitute an event and will occur at the mission time which corresponds to the system failure time plus the system downtime. The system reaction time will replace the time of the system failure in the event controller.

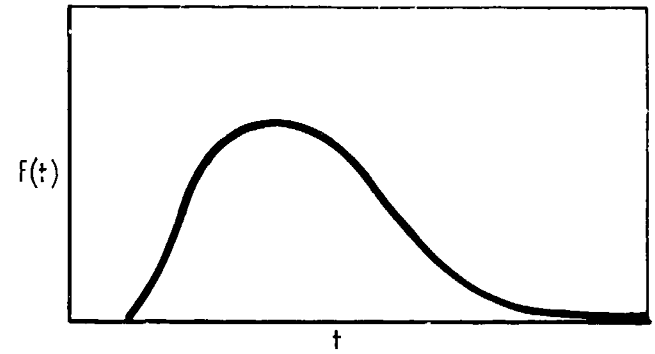
The third type of entry into the random event generation routine is made when the program advances to an event such as a systems reactivation after a failure enforced downtime. Under this mode of entry, subroutine REG(C) is used to determine the new event occurrence time for the system that is being reactivated. This new event time replaces the previous event time, which was the system reactivation time. If this new event time exceeds the mission duration, no additional failures will occur in that system. However, if the new event time is less than the mission duration another system failure will be simulated for that system.

11.5 Mechanics of the Random Event Generation Routine

Two classes of probability distributions are considered in the Space Station Model: (1) discrete distributions $p(x_1,...,x_k)$ which are used to describe the likelihood of each one of the possible outcomes for a particular phenomena and (2) continuous distributions $f(t)$ which are used to describe the likelihood of a particular phenomena occurring as a function of some continuous variable. The mechanics used in simulation of these pehnomena are presented below.

11.5.1 The Continuous Variable

In the case of the continuous variable, the likelihood of the random event occurring at any time t is described by some known probability density function f(t). For purposes of exposition f(t) is considered to be the three parameter Weibull distribution, as shown in Figure 11-4. The associated distribution function F(t)

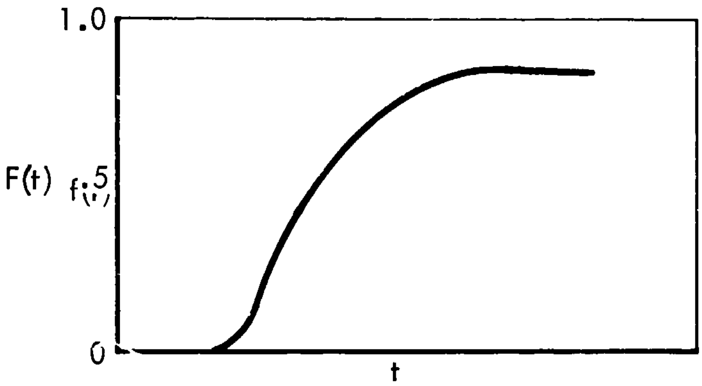


$$f(t) = \alpha\beta\,(t-a)^{\beta-1} \quad \exp\left[-\alpha(t-a)^{\beta}\right]$$

$$t \geqslant a$$

$$a,\ \alpha\ ,\beta \geq 0$$

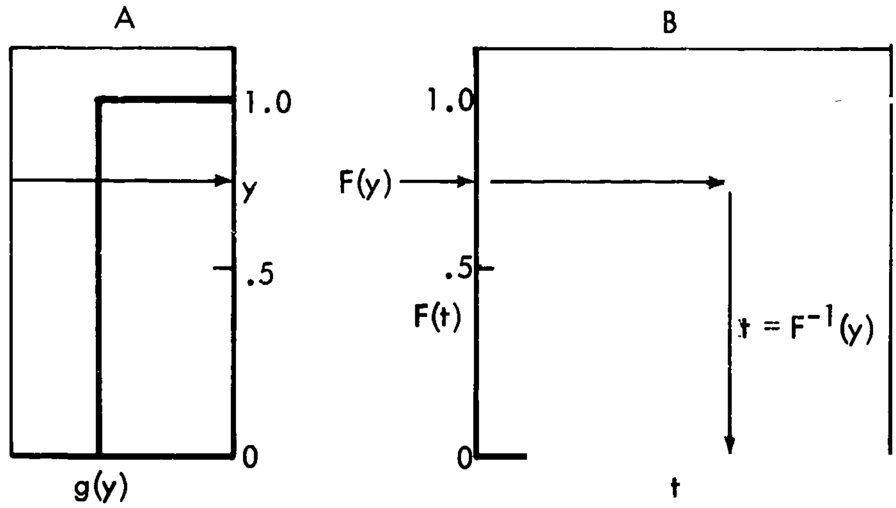
Figure 11-4 PROBABILITY DENSITY FUNCTION (EXAMPLE)



$$F(t) = 0$$

$$F(t) = 1 - e^{-\alpha(t-a)^{\beta}}$$

Figure 11-5 PROBABILITY DISTRIBUTION FUNCTION (EXAMPLE)



A: y is a uniform variate over the range 0 to 1

B: t is a continuous variate over the range 0 to ∞

Figure 11-6 INVERSE PROBABILITY INTEGRAL TRANSFORMATION

describes the probability that the random event occurs on or before time t as shown in Figure 11-5.

Simulating the operation of the phenomena described by f(t) is accomplished by selecting a random variable from the distribution f(t). Application of the "inverse probability integral transformation" provides a method for selecting a random variable from any continuous distribution function f(t). The mechanics of the procedure for determining the time t at which the random event occurs are

- Draw a random number, y, from the uniform distribution (A)
- The analytical expression of F(t) is set equal to the observed value of y
- The resulting equation is solved for the event occurrence time t. (See Figure 11-6.)

The "inverse probability integral transformation" method of simulating an experiment is applicable to both continuous and discrete variables. In either case only the distribution function of the variable under study is needed. The distribution function can be given in either a tabular or an analytical form; however, obvious simplifications can be made if restricted to the case of the analytical expression. In the case of most variables, the entire problem can be reduced to that of solving a simple equation to determine the event occurrence time.

Following the procedure outlined above for a Weibull variate,

$$y = F(t) = 1 - \exp\left[-\alpha(t-a)^{\beta}\right]$$

$$t = a + \left(\left[-\ln(1-y)\right] / \alpha\right)^{1/\beta}$$

where

y	is a random 0 - 1 uniform variate
a, α, and β	are distribution parameters
t	is the time of event occurrence.

11.5.2 The Discrete Variable

The discrete distribution is used to simulate those phenomena whose outcome must fall into one of K mutually exclusive categories. In this case the probability density function $p(x_1,\ldots,x_k)$ describes the likelihood of each one of the possible categories or outcomes. The "inverse probability integral transformation" is applicable to discrete variables as well as continuous. Thus, the same methodology can be used to determine the outcome of either continuous or discrete variable phenomena.

11.5.3 Distributions for Representing Random Phenomena

In simulating the various probabilistic phenomena, each phenomena is assigned a probability density function. A survey of the probabilistic events associated with space stations operations revealed the requirement for a large selection of probability density functions (p.d.f.) to describe the random phenomena. Consequently, eight distributions were provided. These distributions are depicted in Figure 11-7 along with the number of input parameters required for each distribution and the anticipated use of each. In many cases only a single input parameter is required and no case requires more than three parameters.

In the random event generation routine library, each random phenomena has been assigned a distribution type and the necessary distribution parameters required to describe that phenomena. The eight distribution types available, the parameters of each distribution, and the equation obtained from the inverse probability integral transformation (IPIT) are described in the following paragraphs:

I <u>Weibull Distribution</u>

(p.d.f.) $$f(t) = \alpha\beta(t-a)^{\beta-1} \exp\left[-\alpha(t-a)^{\beta}\right]$$

$$t \geq a$$

$$a, \alpha, \beta \geq 0$$

(IPIT) $$t = a + \left(\left[-\ln(1-y)\right] / \alpha\right)^{1/\beta}$$

II <u>Exponential Distribution</u>

(p.d.f.) $$f(t) = \alpha \exp\left[-\alpha t\right]$$

$$t \geq 0$$

$$\alpha \geq 0$$

(IPIT) $$t = \left[-\ln(1-y)\right] / \alpha$$

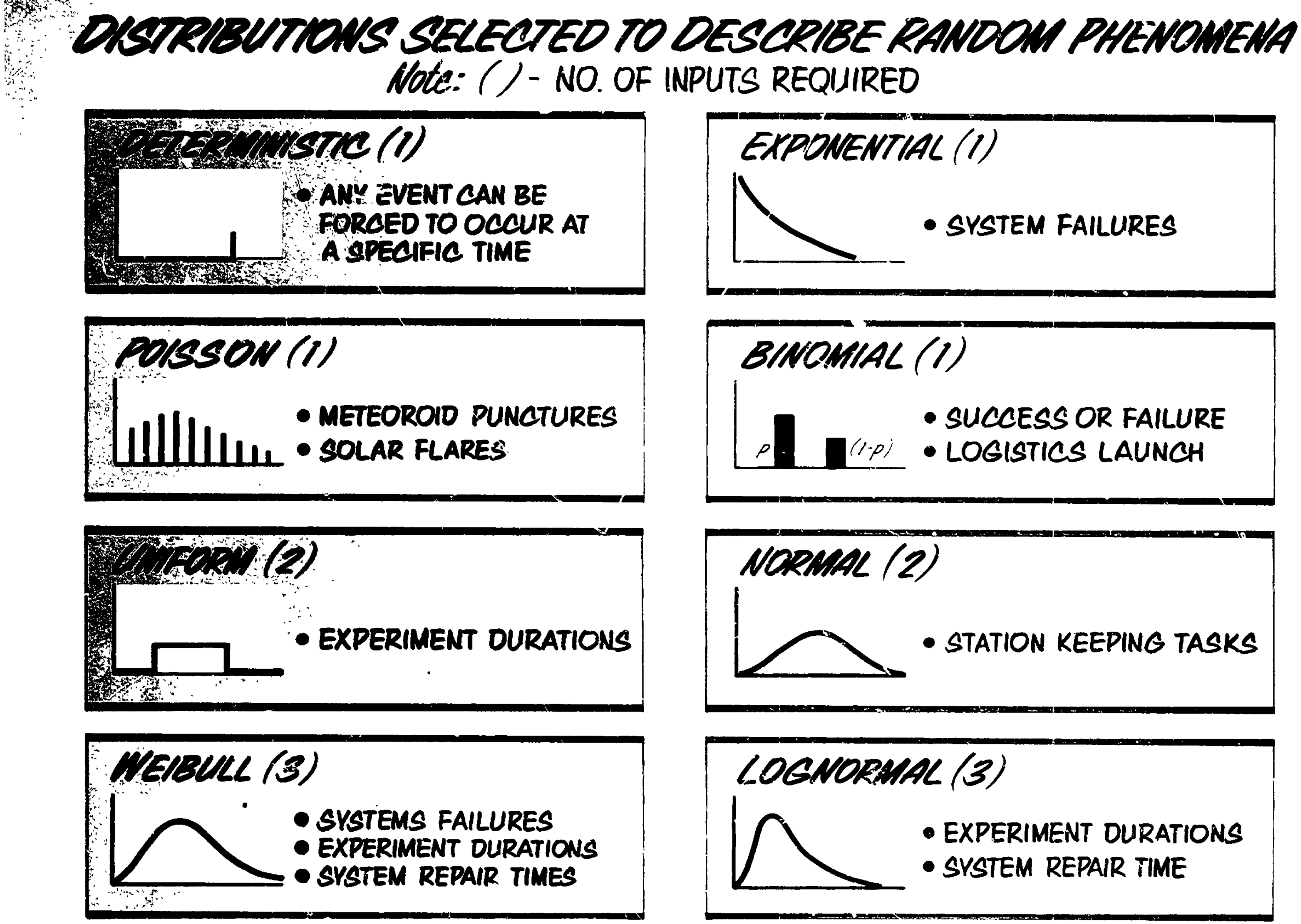

DISTRIBUTIONS SELECTED TO DESCRIBE RANDOM PHENOMENA
Note: ( ) - NO. OF INPUTS REQUIRED
DETERMINISTIC (1)
• ANY EVENT CAN BE FORCED TO OCCUR AT A SPECIFIC TIME
EXPONENTIAL (1)
• SYSTEM FAILURES
POISSON (1)
• METEOROID PUNCTURES
• SOLAR FLARES
BINOMIAL (1)
P
(1-P)
• SUCCESS OR FAILURE
• LOGISTICS LAUNCH
UNIFORM (2)
• EXPERIMENT DURATIONS
NORMAL (2)
• STATION KEEPING TASKS
WEIBULL (3)
• SYSTEMS FAILURES
• EXPERIMENT DURATIONS
• SYSTEM REPAIR TIMES
LOGNORMAL (3)
• EXPERIMENT DURATIONS
• SYSTEM REPAIR TIME

Figure 11-7

With respect to systems analysis,

α = the failure rate

MTBF = the mean time between failures

α = 1/MTBF.

III Uniform Distribution

(p.d.f.) $f(t) = \dfrac{1}{\beta - \alpha}$

$$\alpha \leq t \leq \beta$$

$$0 \leq \alpha < \beta$$

(IPIT) $t = \alpha + y(\beta - \alpha)$

IV Normal Distribution

(p.d.f.) $f(t) = \dfrac{1}{\sqrt{2\pi}\beta} \exp \left[- \frac{1}{2} \quad \dfrac{t - \alpha}{\beta} \right]$

$$-\infty < t < +\infty$$

$$\alpha, \beta > 0$$

(IPIT) $t = \alpha + y'\beta$

Computer subroutines exist for generating a random standard normal deviate y'. When the normal and lognormal distributions are involved, it is more efficient to use these subroutines than to ignore them. Thus, for the normal and lognormal distributions, a random standard normal deviate is selected by use of an existing subroutine and then converted into the event occurrence time as shown.

V Lognormal Distribution

(p.d.f.) $f(t) = \frac{1}{(t-\gamma)\sqrt{2\pi}\,\sigma} \exp -\frac{1}{2} \frac{\ln(t-\gamma)-\mu}{\sigma}^2$

$t \geq \gamma$

$\mu \geq \sigma$

$\sigma > 0$

(IPIT) $t = \alpha + \exp\left[\mu + y'\sigma\right]$

where

$$\sigma = \frac{1}{1.645} \quad \ln(\beta-\alpha) - \ln(\alpha - a)$$

$$\mu = \ln(\alpha - a) - \ln(1 - \exp\left[-1.645\sigma\right])$$

$$\gamma = \alpha - \exp\left[\mu\right]$$

It is anticipated that the lognormal distribution will be used for most of the systems repair time distributions and a high percentage of the experiment completion time distributions. When dealing with research and development efforts such as this study is there is considerable difficulty involved in directly estimating the parameters of the lognormal distribution. Consequently, rather than making direct estimates of the distribution parameters, estimates of various distribution percentage points are made. These percentage points a, α, β are then converted by the computer program into the required distribution parameters. The percentage point estimates are obtained from the following three qualitative estimates:

1. Optimistic Time ($a = P_{0.05}$)

2. Most Likely Time ($\alpha = P_{0.50}$)

3. Pessimistic Time ($\beta = P_{0.95}$)

The first estimate, a, is an "optimistic" one; it gives the best or shortest time which might occur if the activity progresses at or near its fastest possible rate. The "most likely" time estimate, α, is that time which can be expected to occur most frequently. The "pessimistic time" estimate, β, is that time which would occur if the activity progresses at or near its slowest possible rate. These qualitative estimates are taken to be the 0.05, 0.50, and 0.95 percentile points in the derivation of the equations for the distribution parameters.

VI Poisson Distribution

(p.d.f.) $$P(K) = \frac{(\alpha T)^K}{K!} \exp\left[-\alpha T\right]$$

$K = 0, 1, 2, \ldots$

$T \geq 0$

(IPIT) $$t = \left[-\ln(1 - y)\right] / \alpha$$

The Poisson distribution is based upon a constant likelihood of occurrence for the phenomena under study and expresses the probability of K occurrences within a fixed time interval T. Thus the Poisson distribution represents an exponential situation which has been evaluated for a specified interval of time. Consequently, in order to determine the time until the first event occurrence the "inverse probability integral transformation" is not applied to the Poisson distribution but rather to an exponential distribution with a rate parameter α , equal to the rate parameter α of the Poisson distribution.

VII <u>Binomial Distribution</u>

(p.d.f.)	$p(x) = \alpha$		$x = 1$
	$p(x) = 1 - \alpha$		$x = 0$
(IPIT)	$x = 1$	$y \leq \alpha \Rightarrow$	successful outcome
	$x = 0$	$y > \alpha \Rightarrow$	unsuccessful outcome

The binomial situation occurs when the event occurrence time is known and the question to be answered is whether or not the outcome of the event is successful or unsuccessful.

VIII <u>Deterministic</u>

$$t = \alpha$$

One of the anticipated uses of the Space Station Model is to provide a tool for answering "what if" questions. With respect to the random events, this implies that the model must have the capability to force the "normally random events" to occur at any specified time and have any specified outcome.

The input parameters of the binomial distribution can be altered to force a desired outcome and the deterministic relationship can be used to force the events to occur at any desired time.

12.0 ERROR ANALYSIS

12.1 Introduction

In the Simulation Mode of the Space Station Model there are three areas in which errors may be introduced. Since the objective in constructing the Space Station Model is to provide a tool for use in program planning, the recognition of errors and the control of error effects is an important part in development and use of the model.

The three areas in which errors may be introduced are (1) in the input parameters and estimating relationships, (2) in the internal mathematical computations, and (3) in the data analysis based upon the Monte Carlo simulation results (see Figure 12-1). Obviously, the term "error" does not mean precisely the same thing in each of the cases listed above. Consequently, each of the cases is considered separately.

12.2 Types of Model Errors

12.2.1 Input Parameters and Estimating Relationships

Two types of problems must be considered in assessing the error effects associated with the input parameters and estimating relationships: (1) the case where the input parameters and estimating relationships are derived from a statistical data analysis,

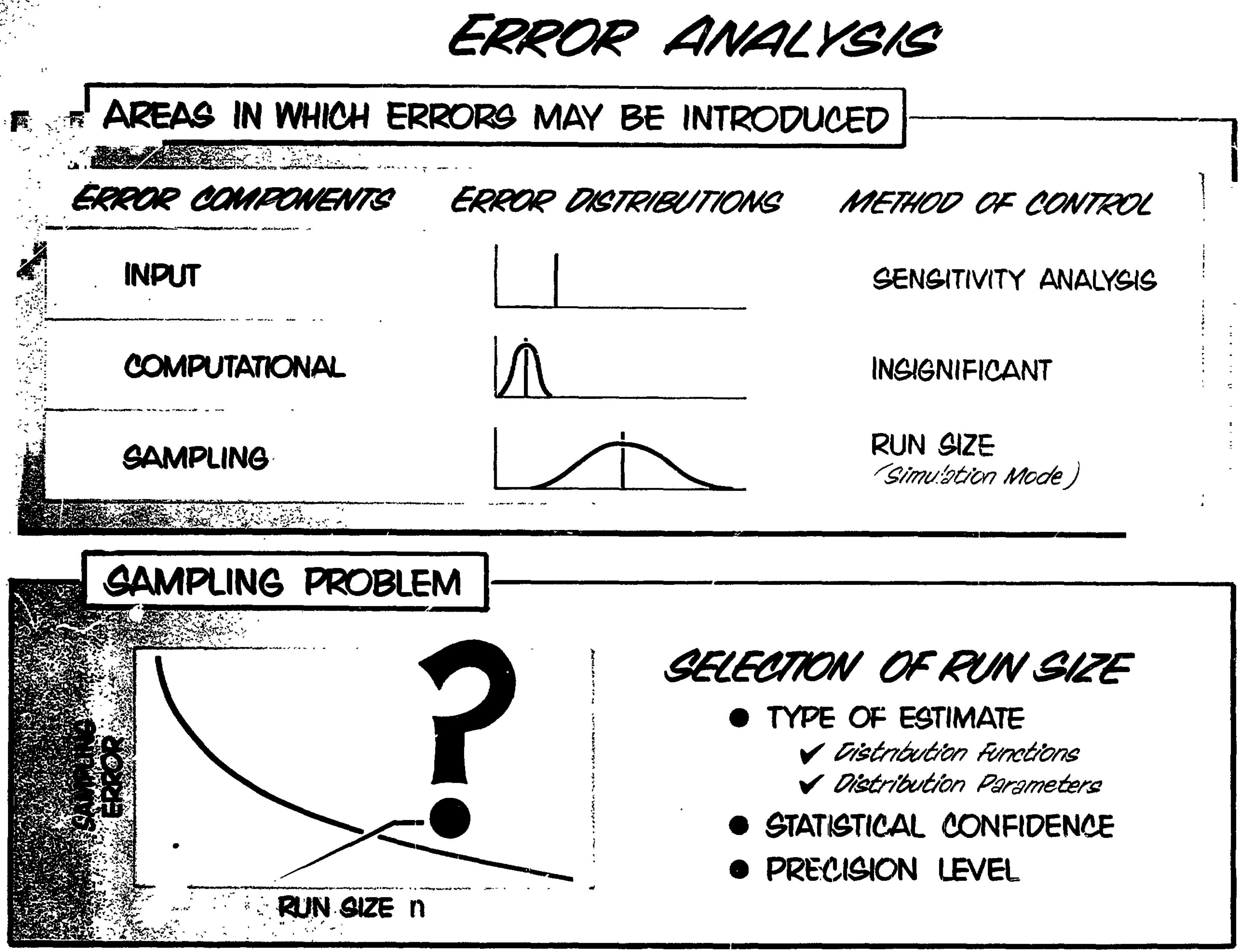

ERROR ANALYSIS
AREAS IN WHICH ERRORS MAY BE INTRODUCED
ERROR COMPONENTS
ERROR DISTRIBUTIONS
METHOD OF CONTROL
INPUT
SENSITIVITY ANALYSIS
COMPUTATIONAL
INSIGNIFICANT
SAMPLING
RUN SIZE
(Simulation Mode)
SAMPLING PROBLEM
SAMPLING ERROR
RUN SIZE n
SELECTION OF RUN SIZE
● TYPE OF ESTIMATE
✔ Distribution Functions
✔ Distribution Parameters
● STATISTICAL CONFIDENCE
● PRECISION LEVEL

Figure 12-1

and (2) the case where the input parameters and relationships are derived from systems considerations and engineering estimates. In order to perform a statistical error analysis of the input parameters and functional relationships, these estimates must be derived from existing systems for which there exist operational data. This is not the case encountered in development of the Space Station Model. Consequently, the error analysis in this phase of the study is not the conventional error analysis associated with statistical modeling. That is, in the Space Station Model the case encountered involves developing relationships for a system where little if any empirical data exist. Thus, the error associated with the input data is a constant for any particular problem and is not associated with the model itself. The effect of the input error upon the mission effectiveness measures can be determined by a sensitivity analysis of the input data. The sensitivity analysis of the input parameters and estimating relationships will be accomplished during actual use of the model. Provisions are included in the Space Station Model for rapid alteration of input parameters and estimated functional relationships contained in the library data.

12.2.2 Internal Mathematical Computations

When all input data and the model relationships are exact (input error free), mechanical or computational errors can still be introduced and propogated by such factors as round off, series truncation, etc. In development of the Space Station Model the effects of mechanical errors are not significant.

12.2.3 Random Sampling Errors

Any model developed to simulate the operations of a manned space station must possess the capability to evaluate many stochastic variables with complex interactions. These interactions and their effects upon the simulated system and its operations impose a degree of complexity which seriously limits if not renders impractical the use of "closed form" mathematical modeling. The Monte Carlo simulation technique has been incorporated in the Space Station Model to provide the capability for analyzing these interacting effects. In this method, the set of all possible events and the set of all possible station states must be defined. Then, the computer program proceeds directly from one event to the next, altering the station status as required by each event and maintaining a record of event occurrence times and event outcomes.

The Monte Carlo simulation analysis of such a system can be compared to the development and processing of a sophisticated network analysis. The nodes of the network correspond to the events of the space station. The Monte Carlo simulation is accomplished as follows.

At the initiation node of the network the system is placed in some predetermined status (e.g., ready for launch), the computer program now advances in mission time to the first node of the network. At this node (launching of the laboratory, for example) a single stochastic variable is examined. Given the value of this variable, its effect upon the system must be determined. Once the effect upon the system is determined the system status is modified accordingly. Now the stage is set for movement to a new node in the network. Several nodes may be reached directly from the first node. The selection of the next node to be advanced to is dependent upon the stochastic variable observed at the first node and its effect upon the system. That is, the path which is to be followed upon leaving any node is dependent upon the stochastic variable which was observed at that node. Each possible path, starting at the first node and ending at the last node, represents a possible outcome of the Space Station program. Thus, a single replication of the Monte Carlo simulation model is nothing more than observing one of the many possible outcomes of a space station program. Obviously a single replication has limited use in analyzing systems or operational concepts of any program. Since a single replication is not meaningful for planning purposes the obvious question is, how many replications are required to obtain data which are meaningful for planning purposes?

Determination of the number of computer runs (one computer run is a single replication) required to obtain useful planning information from a Monte Carlo simulation model can be obtained by statistical sampling considerations. Since the effectiveness measures under study have sampling distributions dependent upon the structure of the simulation model and its various parameters, it is not possible to know the absolute accuracy of any estimate based upon an analysis of the simulation results. However, it is possible to make probabilistic accuracy statements. That is, specific statements concerning the effectiveness measure under study can be made provided the likelihood of these statements being correct is also given.

On subsequent pages, methods are set forth for recognition and control of the Monte Carlo sampling error and nomographs are provided for use in selecting run sizes for the Simulation Mode. The run size required in the Simulation Mode is dependent upon (1) the type of estimates being made, (2) the statistical confidence level desired, and (3) the estimate precision required. Both the statistical confidence level and the precision associated with any estimate are measures of the Monte Carlo sampling error and can be controlled by the simulation run size. The two types of estimates which will be made from the analysis of simulation results are estimates concerning a parameter of the variable under study and estimates regarding the distribution of the variable itself. The statements of accuracy concerning these two situations are discussed in Subsections 12.3 and 12.4.

12.3 Confidence Intervals

Confidence intervals are associated with the problem of estimating parameters of a probability distribution. By employing confidence intervals it is possible to specify an interval, about the point estimate, that will have some specified probability of including the true value of the parameter being estimated. The boundary values of such intervals are called the confidence limits of the parameter, while the interval itself is called the confidence interval for the parameter. The confidence coefficient is the relative frequency with which the confidence interval will contain the true value of the parameter (in the sense that if many estimates of the parameter are made, the corresponding confidence intervals associated with these estimates will contain the true value of the parameter in a portion of times equal to the value of the confidence coefficient). Thus, a γ % confidence interval for a parameter indicates that the probability is γ that the true value of the parameter being estimated lies within the confidence interval. The confidence coefficient can thus be regarded as a measure of the estimation accuracy achieved by a given run size. The mathematical statement of a confidence interval for the mean of a distribution is

$$P_r(\bar{x} - KS \leq \mu \leq \bar{x} + KS) = \gamma$$

where

γ is the confidence coefficient

$\bar{x}$ is the sample mean

S is the sample standard deviation

μ the parameter being estimated

K is a variable dependent upon γ and the sample size.

Confidence intervals correspond to statements of the type "The probability is γ that the interval ℓ_1 to ℓ_2 contains the true value of the population parameter.

12.3.1 Confidence Intervals Based Upon a Normal Distribution

A commonly used model to determine sample size requirements is the normal distribution. If this model represents the random variable under study then Figure 12-2 can be used to determine the sample size required to obtain specified confidence and precision levels, where precision is taken to be the width of the confidence interval. To make use of Figure 12-2 for sample size selection, a confidence coefficient (e.g., γ = 0.90) and a precision level

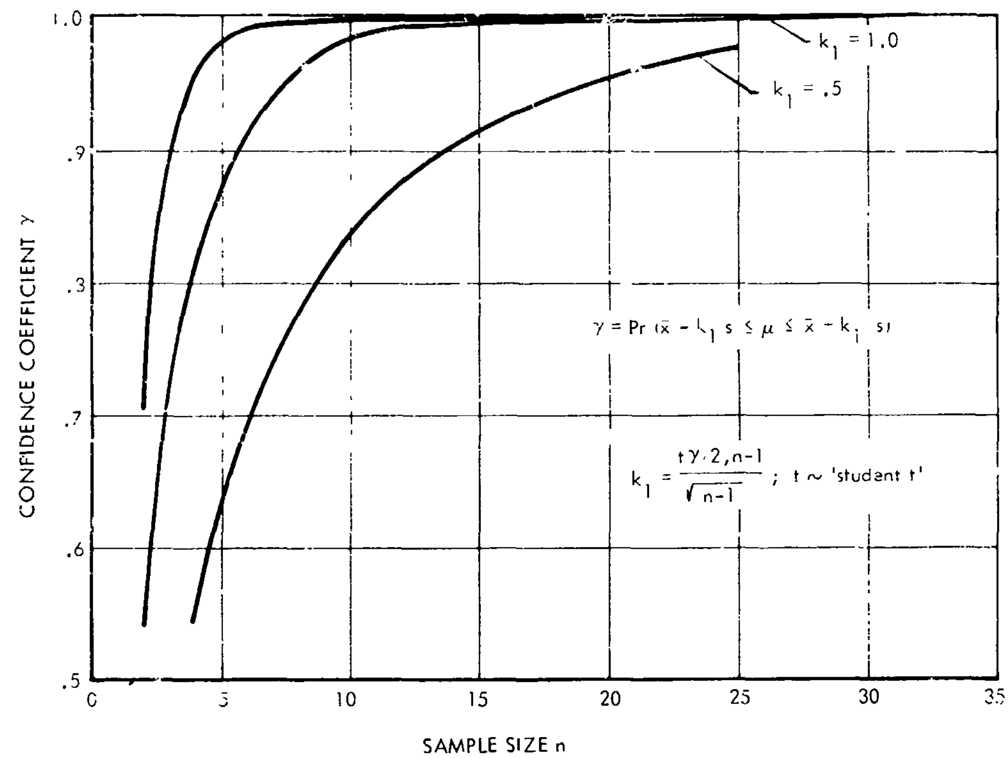


Figure 12-2 CONFIDENCE INTERVALS NORMAL DISTRIBUTION WITH UNKNOWN MEAN AND VARIANCE

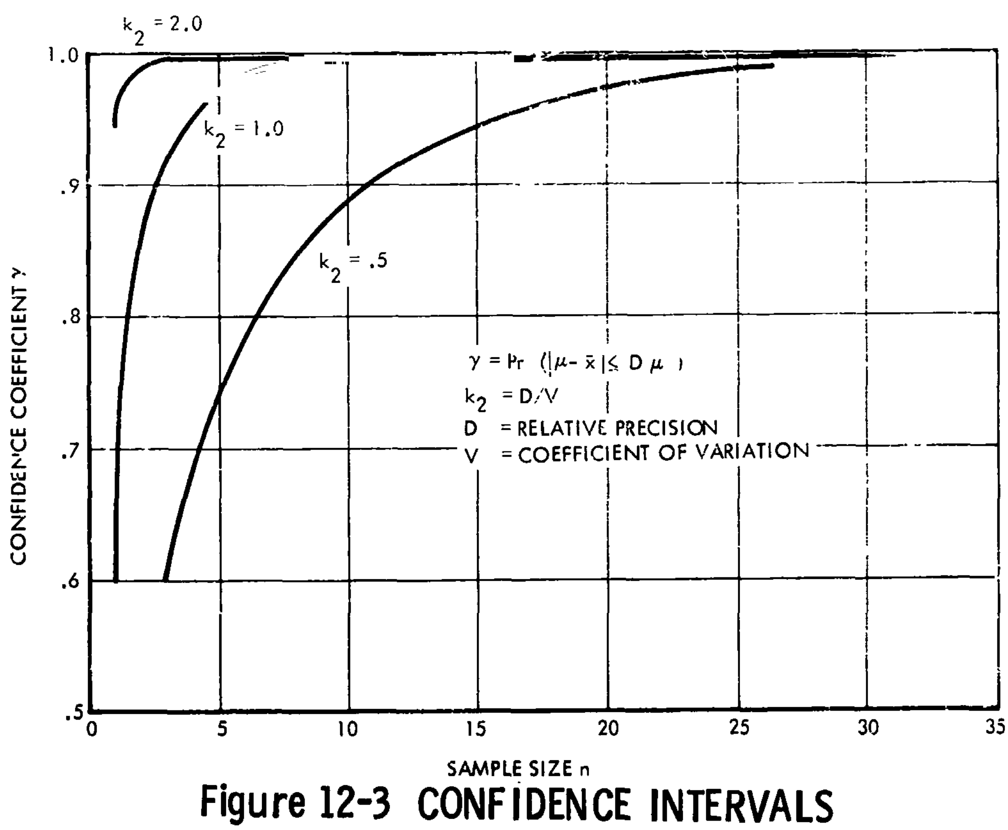


Figure 12-3 CONFIDENCE INTERVALS NORMAL DISTRIBUTION WITH KNOWN COEFFICIENT OF VARIATION FIXED (D/V) RATIO

(e.g., $K_1 = 0.5$) are specified and the corresponding sample size ($n = 14$) is noted. When the sample of 14 has been taken the following statement can be made. The probability is 0.90 that the interval $\bar{x} - 0.50S$ to $\bar{x} + 0.50S$ contains the true value of the mean, μ, where $\bar{x}$ and S are estimates of the mean and standard deviation computed from the sample data.

Figure 12-2 contains three parameters: the confidence coefficient, γ, the precision level K_1, and the sample size n. In the example above γ and K_1 were specified and n determined. However, any two of the parameters may be specified and the third determined.

12.3.2 Confidence Intervals Based Upon a Normal Distribution (Known Coefficient of Variation)

In the preceding paragraph, the only a priori information available about the random variable under study was that it could be modeled with a normal distribution. Frequently additional information concerning the relative variability of the variable is available or can be obtained. If so this additional a priori information can be used to reduce sample size requirements. The quantitative measurement used for denoting the relative variability of a random variable is termed the coefficient of variation. The coefficient of variation is the ratio of the standard deviation to the mean, i.e., ($V = s/\bar{x}$). When this information is available the sampling problem may be formulated as follows: what sample size is required to achieve a γ % confidence that the sample mean, $\bar{x}$, is within $\pm$ D% of the population mean. Figure 12-3 can be used to answer such questions. For example, if the coefficient of variation is estimated to be 0.2, the sample size required to achieve a 90% probability that the sample estimate, $\bar{x}$, will be within $\pm$ 10% of the true mean is n = 11. Three parameters are noted in Figure 12-3: the confidence coefficient γ, the sample size n, and a K_2 factor which is the ratio of the precision desired to the coefficient of variation, i.e., $K_2 = D/V$. Thus, to determine the sample size, a confidence coefficient is selected, K_2 is calculated from the coefficient of variation and desired precision, and the corresponding n is read from the graph.

This particular sampling model is commonly used because, for the larger sample sizes, the normality requirement of the parent distribution is not required. This is possible because of the central limit theorem, which states in essence, that the distribution of sample means tends toward the normal distribution regardless of the nature of the parent distribution. The equation for sample size determination of such a model is

$$n = \left(\frac{KV}{D}\right)^2$$

where

- n = the sample size
- D = the relative precision desired
- V = the coefficient of variation and
- K = the standardized normal deviate corresponding to the desired confidence coefficient.

Figure 12-4 is a plot of the sample size required to achieve varying confidence coefficients as the ratio of the coefficient of variation to the relative precision, (V/D), is varied. To make use of this figure, a precision level and a confidence coefficient are selected; the ratio of (V/D) is calculated; and the required sample size is then observed. When the sample of n is taken and the mean, $\overline{x}$, is calculated the following statement can be made: "The probability is γ % that $\overline{x}$ is within $\pm$ D% of the true mean.

12.3.3 Confidence Intervals for Distribution Functions

An estimate which is frequently made from simulation data is that of the distribution function of the variable under study. In Figure 12-5 an estimated distribution function and its associated confidence interval are depicted. The type of statement which can be made from such a confidence interval is "The probability is γ that the interval $F_a(x)$ to $F_b(x)$ contains the true value of F(x). Figure 12-6 represents the relationship between the confidence, coefficient γ, the sample size, n, and the precision of the

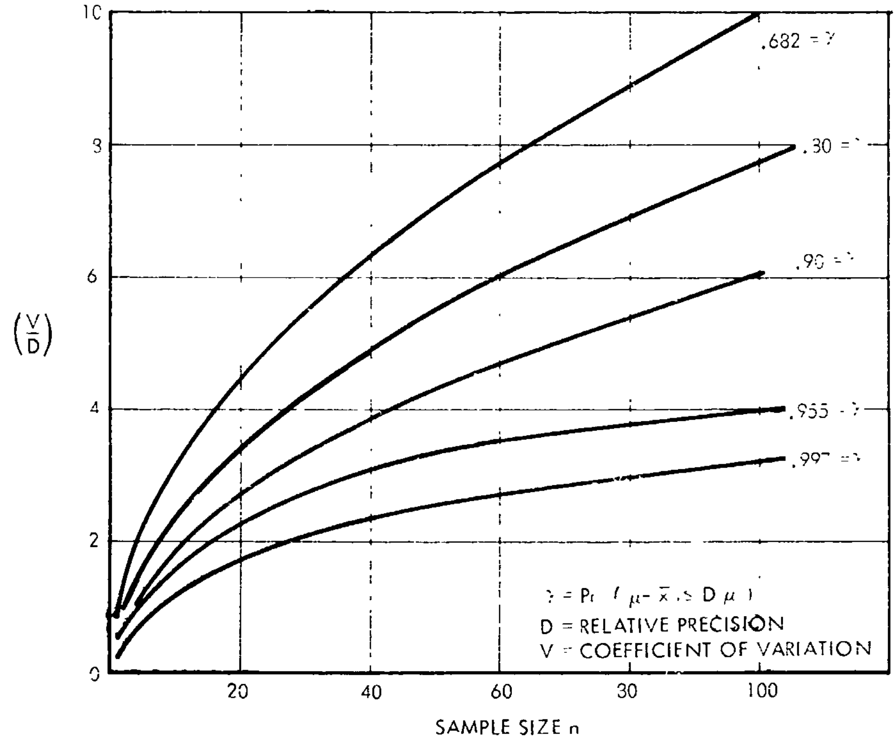


Figure 12-4 CONFIDENCE INTERVALS NORMAL DISTRIBUTION WITH KNOWN COEFFICIENT OF VARIATION PARAMETRIC (V/D) RATIO

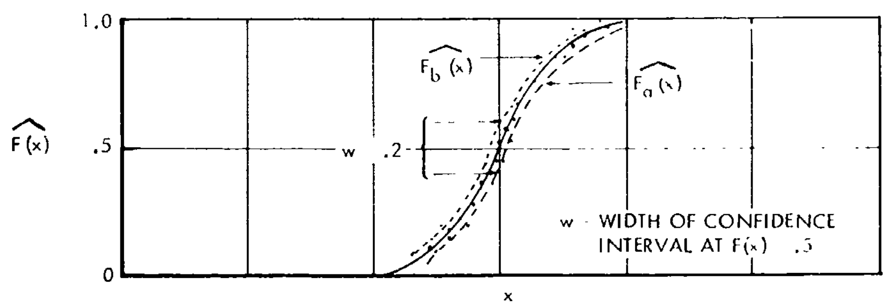


Figure 12-5 NONPARAMETRIC CONFIDENCE INTERVALS FOR DISTRIBUTION FUNCTIONS

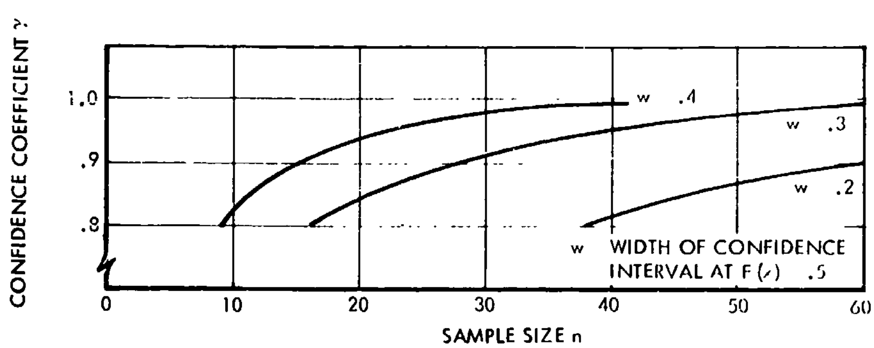


Figure 12-6 CONFIDENCE COEFFICIENT AND INTERVAL WIDTH VS. SAMPLE SIZE

interval estimate, where precision is defined to be the width of the confidence interval at $F(x) = 0.5$. This figure may be used to determine the sample size required to obtain a specified confidence level and precision for an interval estimate of a distribution function.

To make use of Figure 12-6 in determining sample size, a confidence coefficient (e.g., $\gamma = 0.90$) and a precision level (e.g., $W = 0.2$) are selected and the corresponding sample size ($N = 60$) is noted. When the sample of 60 has been taken, an estimated distribution function and its corresponding confidence interval may be computed as illustrated in Figure 12-6. The mechanics involved in this computation are presented in detail in Reference 16.

It should be noted that no assumptions regarding the distribution of the variable are required for this type of confidence interval.

12.4 Tolerance Intervals

Tolerance intervals are associated with the problem of estimating the outcome of the random variable under study and not the parameters of the random variable, as was the case for the confidence intervals. It is possible, by employing tolerance intervals to specify, for a given confidence level, an interval for which the probability is at least P that all future observation on that variable will be within these limits. Tolerance limits reflect an interval of the variables range within which a certain percent, P, of all observations will lie, while the confidence coefficient, γ, indicates the validity of this statement in terms of relative frequency of correct statements.

The mathematical statement of a tolerance interval for a random variable is

$$P_r \left\{ \left[P_r(\ell_1 \leq x \leq \ell_2) \geq P \right] \right\} = \gamma$$

where γ is the percent of computed intervals ℓ_1 to ℓ_2 that will include at least P percent of the observations on the random variable. The tolerance limits ℓ_1 and ℓ_2 are computed sample statistics.

It is important to keep in mind that confidence intervals are probability statements concerning specified parameters of a distribution while tolerance intervals pertain to probability statements concerning the random variable itself.

Thus, confidence intervals correspond to statements such as "The probability is γ that the interval ℓ_1 to ℓ_2 contains the true value of the population parameter." Tolerance intervals correspond to statements such as "The probability is γ that at least P percent of the observations on the variable will lie between ℓ_1 and ℓ_2."

The two types of intervals should be carefully distinguished. Selection of the interval type to be used depends, of course, upon the type of statement to be made.

12.4.1 Tolerance Intervals Based Upon a Normal Distribution

The first sample size selection for the construction of tolerance intervals is based upon the normal distribution model. If this model represents the random variable under study, then Figure 12-7 can be used to determine the sample size required to obtain a specified confidence that at least P% of the random variable lies within the sample determined tolerance interval. To determine sample size requirements from Figure 12-7 a confidence coefficient (γ = 0.90), a precision level (K = 2.0), a percent containment (P = 0.90) are selected and the corresponding sample size (n = 35) is noted. When the sample of 35 has been taken, the following statement can be made. The probability is 0.90 that 90% of all future observations on the random variable will lie in the interval $\overline{x}$ - 2.00S to $\overline{x}$ + 2.00S, where, $\overline{x}$ and S are estimates of the mean and standard deviation computed from the sample data. Figure 12-7 contains four parameters: the confidence coefficient γ, the percentage parameter P, the sample size n, and a precision measure K. Any three of the parameters may be specified and the fourth determined.

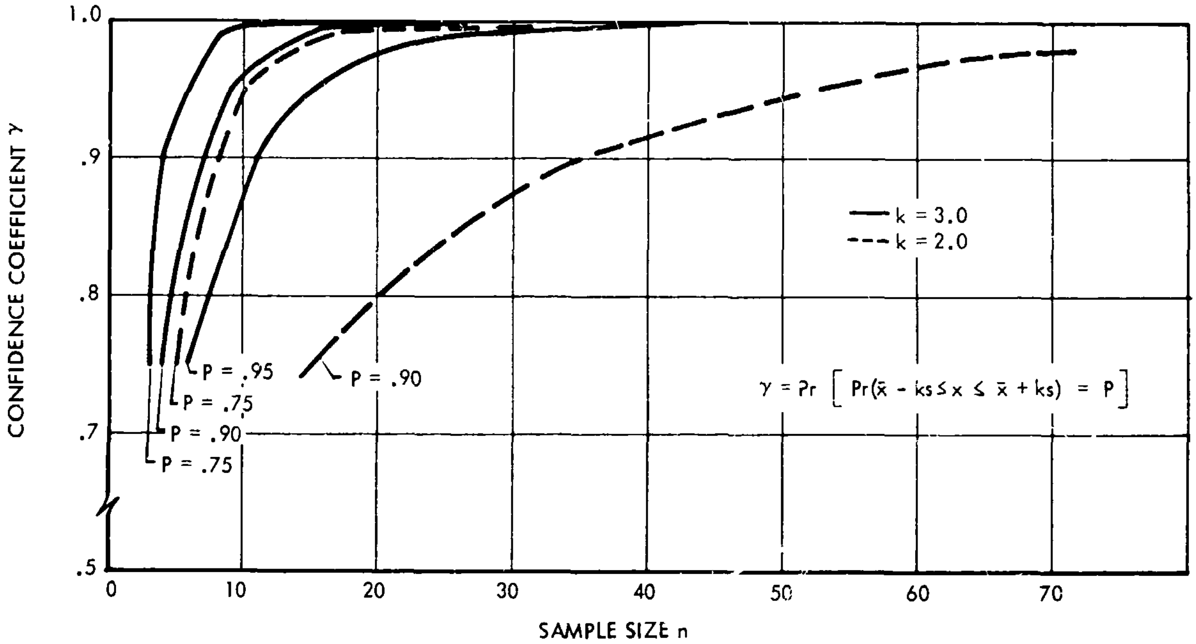


Figure 12-7 TOLERANCE INTERVALS NORMAL DISTRIBUTION WITH UNKNOWN MEAN AND VARIANCE

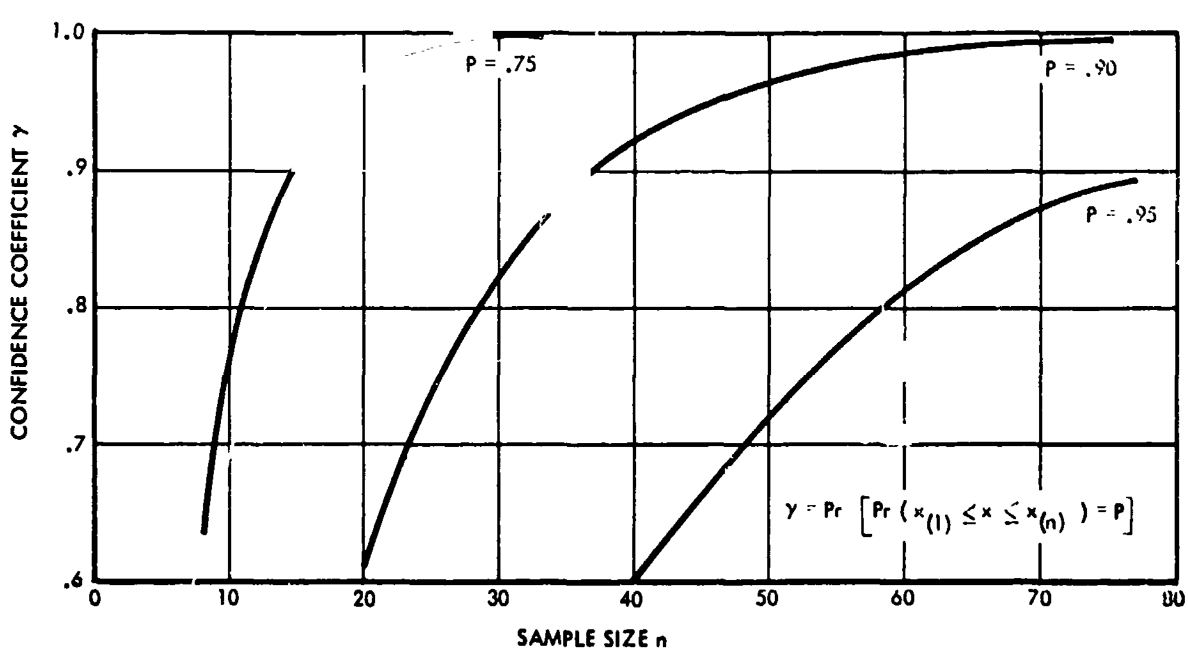


Figure 12-8 NONPARAMETRIC TOLERANCE INTERVALS

12.4.2 Nonparametric Tolerance Intervals

The second type of tolerance interval to be considered does not require the normality assumption. This nonparametric tolerance interval is completely independent of the form of distribution from which the sampling is being done. Figure 12-8 reflects the relationship between the confidence coefficient γ, the percent containment P, and the sample size n, for such a tolerance interval. To make use of Figure 12-8 in determining sample size requirements, a confidence coefficient ($\gamma = 0.90$) and a percentage containment ($P = 0.90$) are selected and the corresponding sample size ($n = 38$) is noted. When the sample of 38 has been taken the following statement can be made. The probability is 0.90 that 90% of all future observations on the random variable will lie in the interval $x_{(1)}$ to $x_{(38)}$ where $x_{(1)}$ and $x_{(38)}$ are the first and 38th order statistics, respectively, from the sample of 38. The width of the tolerance interval in this case is simply the sample range.

12.5 Run Size Selection for the Simulation Mode

The methods of recognition and control of the Monte Carlo sampling error set forth in the preceding pages are applicable to the Simulation Mode of the Space Station Model. Recognition is accomplished by the use of interval estimates, rather than point estimates, and control is provided by means of sample size or number of replications.

The preceding graphs may be used for determining the run sizes and consequently the computer time required for any of the following three cases:

Case I: Given a desired confidence coefficient and precision level, determine the resulting sample size.

This is accomplished by simply selecting the appropriate graph, dependent upon the type of estimate to be made, and looking up the sample size required to achieve the desired precision and confidence coefficient. The required computer run time is then given by the following equation,

$$T = T_1 + nT_2,$$

where T_1 is the fixed time for setting up the program, T_2 is the time per replication, and n is the number of replications required.

Case II: Given a computer run time constraint and a specified precision level, determine the maximum confidence coefficient that can be obtained.

This is accomplished by solving the following equation for the run size n,

$$n = \frac{T_c - T_1}{T_2},$$

where T_c is the run time constraint and T_1 and T_2 are the variables defined above. With this value of n, the appropriate graph, dependent upon the type of estimate to be made, is entered, and the maximum confidence coefficient to be obtained at this specified precision level and run time constraint is observed. This case has been presented as fixing the run time, the precision level, and then determining the resulting confidence coefficient. It is equally appropriate to fix the confidence coefficient and determine the precision level for a constraint on computer run time. In all of the situations considered a trade-off exists between the precision level and the confidence coefficient for a fixed sample size.

Case III: Determine the computer run time which will optimize the simulation cost.

In this situation the optimum run time is that time corresponding to the n for which the ratio of (Δaccuracy/Δ n) is equal to a point of diminishing return. The quantity accuracy gained can be measured in any one of several parameters depending primarily upon the type of interval being considered. For this study, accuracy gained can always be expressed as the increase in the confidence coefficient associated with the interval estimates. Thus, to determine the optimum run time, the appropriate graph for the estimate to be made is selected and the point of diminishing return between the confidence coefficient and the sample size n is determined. The run time is then given by

$$T = T_1 + nT_2.$$

13.0 MISSION EVALUATION

13.1 Introduction

The magnitude and complexity of a space station program precludes the selection of a single effectiveness parameter for mission evaluation. In such a complex program, evaluation requires the consideration of a multiplicity of effectiveness parameters. To provide this evaluation capability, a special routine, the evaluation routine, has been developed for the Space Station Model. The evaluation routine provides a complete summary of the accounting measures required for mission evaluation. This includes both resource requirements such as number of logistics shots, total program cost, etc., and mission accomplishments such as experimental man-hours provided, pounds to orbit, etc. The program cost, resource requirements, and effectiveness measures are presented separately and in various combinations of cost and effectiveness indicies. This provides the model user with evaluation parameters in their original dimensions as well as the combined cost/effectiveness and resource utilization dimensions.

The evaluation routine is composed of two subroutines, one for the Planning Mode and one for the Simulation Mode. In the Planning Mode the evaluation output is a summary of resource requirements and possible accomplishments of the proposed mission plan. In the Simulation Mode the evaluation output is a summary of the actual requirements incurred and accomplishments achieved when a segment of the planned mission is simulated.

13.2 Planning Mode Evaluation Routine

The function of the evaluation routine is to compute, summarize, and present the cost and effectiveness measures of the space station program. In the Planning Mode phase of model operations, the evaluation parameters are indicative of the resource requirements and possible accomplishments for the planned mission of space station operations. The evaluation parameters may be used for making mission and operational concept comparisons. For example, the effects of various logistics systems upon total cost can be determined by analysis of the evaluation data. In terms of operational evaluations, the effects of various experimental programs are reflected in the evaluation routine output. In general, the output of the evaluation routine is a summary of the resource requirements and possible accomplishments of the planned mission.

The evaluation routine of the Planning Mode has been divided into two parts. Part one is the cost analysis of the planned mission. The major categories of cost considered are research and development cost, facilities costs, initial costs and logistics costs. In addition to the cost category printouts, subdivisions within each of the cost categories are also presented.

The second part of the Planning Mode evaluation output is a summary presentation of the program resource requirements (in dimensions other than cost) and the program effectiveness and cost/effectiveness parameters.

13.2.1 Cost Analysis

In the cost analysis, as in the other analyses which were directed toward the formulation of the modeling approach, it was of the utmost importance to establish the appropriate level of detail early in the study. In the cost analysis, the following guidelines were taken:

1. Low input requirements
2. Simple operational irstructions
3. Minimum unnecessary output
4. Provisions for rapid modification of parameters
5. Suitability to primary cost/effectiv ness analyses
6. Sensitivity to basic system or mission changes.

The general approach to the cost analysis is shown in Figure 13-1. Initially, cases were specified to define the spectrum of costing interest. Consideration was given to the span of calendar years, type of space station system concepts, launch vehicles, orbital parameters, and other factors which significantly influence program cost.

In the approach developed, a simple logic could be used in conjunction with the cost arrays which are an integral part of the cost subroutine. The cost arrays consists of cost data generated by running selected points with the Launch Vehicle Cost Model (LVCM) and the Spacecraft Systems Cost Model (SCM). This approach complies with the guidelines by providing a simple procedure which can be easily input and operated and can subsequently be expanded in scope by enlarging the cost arrays.

13.2.1.1 Using the Cost Subroutine - The simplicity of the cost subroutine is evidenced by the relatively few inputs required for use of the subroutine in the Space Station Model. There are only five input values required of the user, as shown in Figure 13-2. Three additional inputs are generated in the Planning Mode. Input values will indicate the type of space station and logistics spacecraft, the operational period (i.e., program length in years), and beginning quantities for the logistics spacecraft (command module and multimission module) and launch vehicles.

DEVELOPMENT OF COST SUBROUTINE

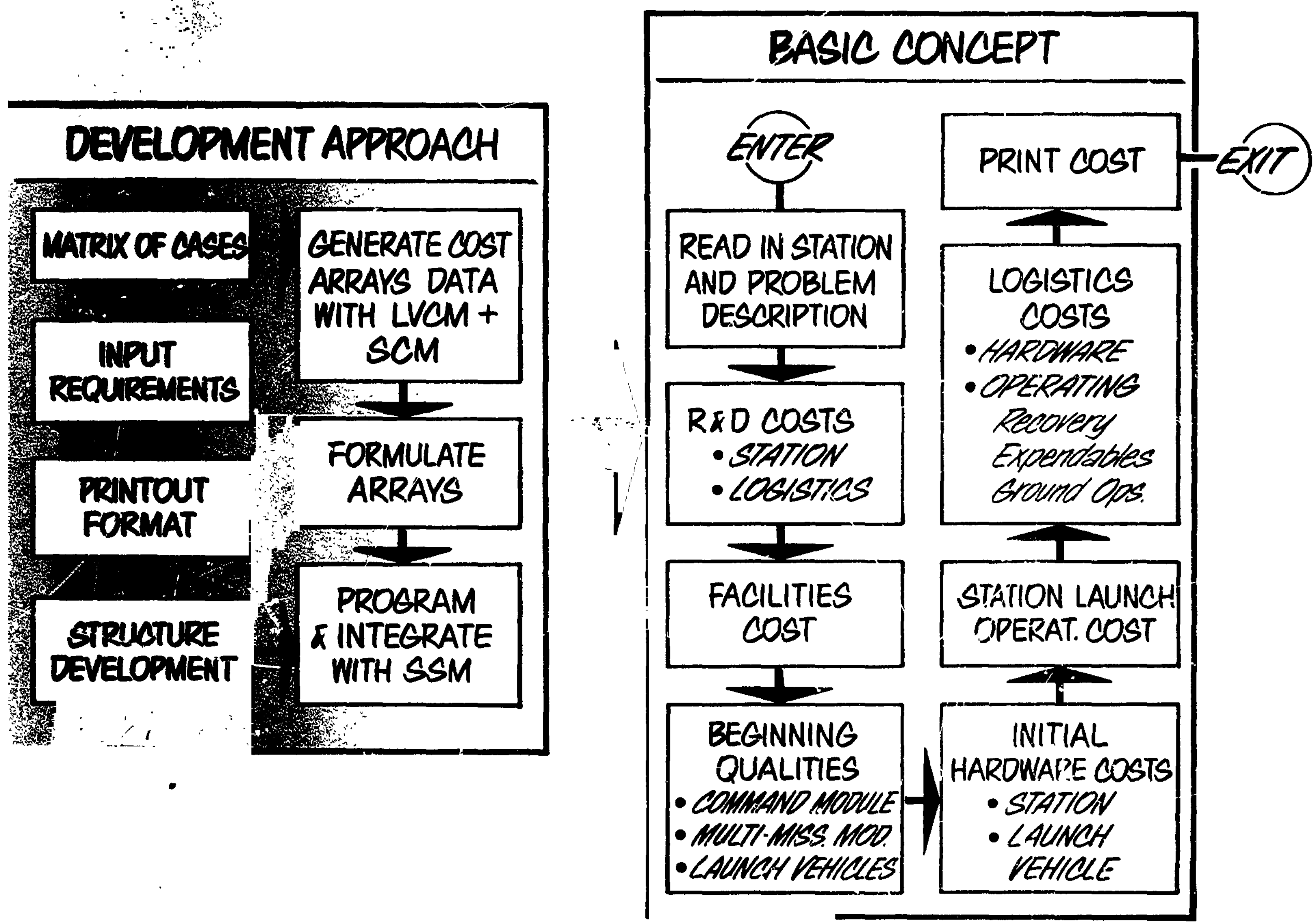


Figure 13-1

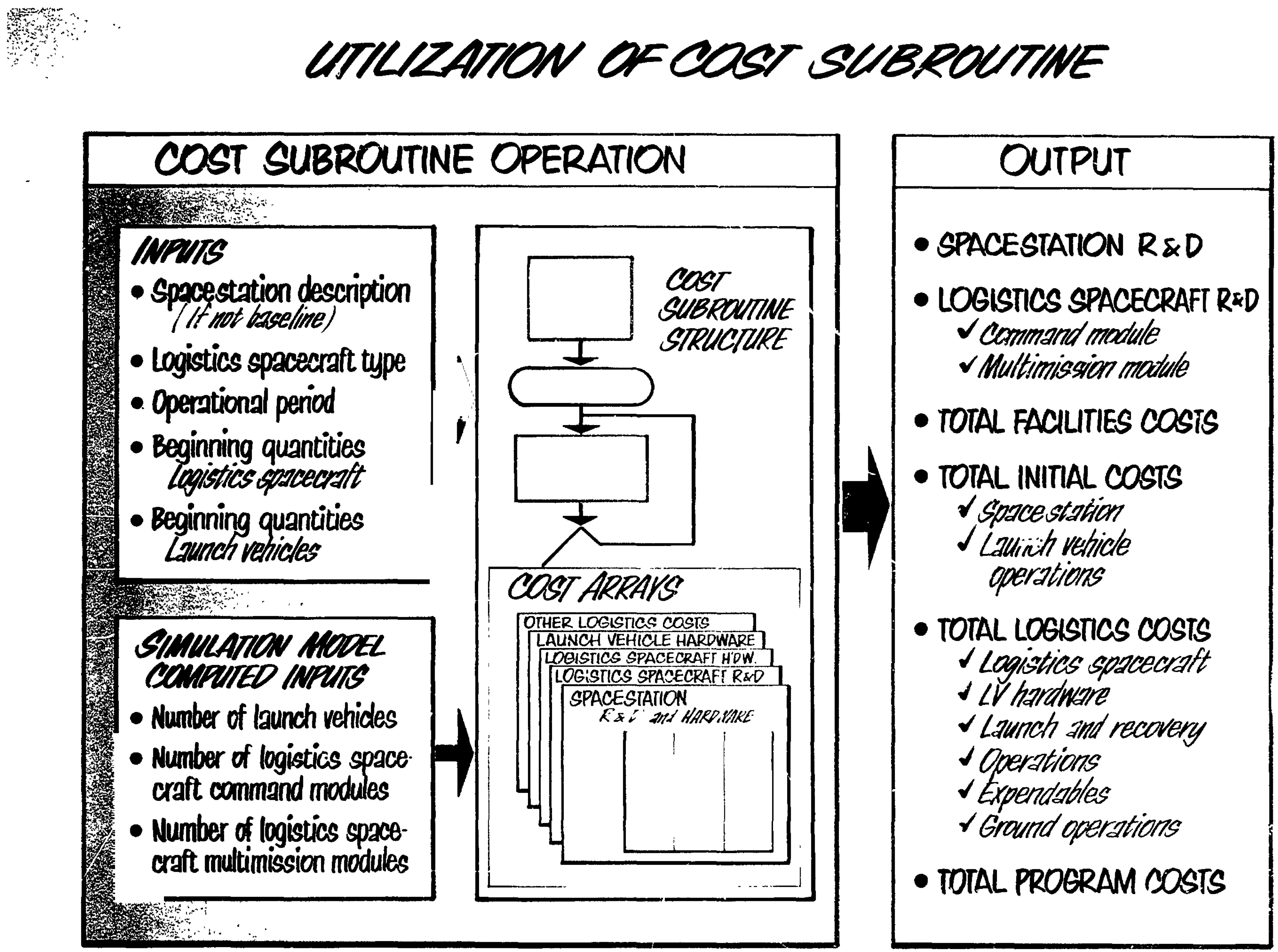

UTILIZATION OF COST SUBROUTINE
COST SUBROUTINE OPERATION
INPUTS
• Spacestation description (If not baseline)
• Logistics spacecraft type
• Operational period
• Beginning quantities Logistics spacecraft
• Beginning quantities Launch vehicles
SIMULATION MODEL COMPUTED INPUTS
• Number of launch vehicles
• Number of logistics spacecraft command modules
• Number of logistics spacecraft multimission modules
COST SUBROUTINE STRUCTURE
COST ARRAYS
OTHER LOGISTICS COSTS
LAUNCH VEHICLE HARDWARE
LOGISTICS SPACECRAFT H'DW.
LOGISTICS SPACECRAFT R&D
SPACESTATION
OUTPUT
• SPACESTATION R&D
• LOGISTICS SPACECRAFT R&D
✓ Command module
✓ Multimission module
• TOTAL FACILITIES COSTS
• TOTAL INITIAL COSTS
✓ Space station
✓ Launch vehicle operations
• TOTAL LOGISTICS COSTS
✓ Logistics spacecraft
✓ LV hardware
✓ Launch and recovery
✓ Operations
✓ Expendables
✓ Ground operations
• TOTAL PROGRAM COSTS

Figure 13-2

Costs may be computed at present for a 28.5 to 50-degree baseline, 90-degree, or synchronous orbit space station through the proper inputs. At present only one logistics spacecraft is in the cost array.

The time period input reflects the number of years that the space station is to be operated and resupplied by the logistics spacecraft. These data are required because some of the logistics costs are computed on the basis of time of operation.

The inputs specifying the beginning quantities of logistics spacecraft and launch vehicles are the final two inputs required of the user. These input values will position the starting point on the learning curve where the cost subroutine should begin to compute logistics hardware costs. Since the quantities of logistics spacecraft and launch vehicles would vary for different time periods and levels of activity in other space programs, it was believed that the user should be free to decide which values would be used.

13.2.1.2 Cost Subroutine Computational Sequence - The computational sequence begins by establishing the R&D cost for the space station, command module, and the multimission module. The cargo module costs represent a basic R&D module cost, with costs for experiment, excursion, and retrofit modules being an added incremental design modification cost.

The subroutine sequentially computes costs beginning with the space station hardware, launch vehicle hardware, and finally the operating costs associated with launching the space station. All of these costs are built into the program in arrays. The hardware cost that appears in the array is for the first production unit.

Launch and recovery operations are computed from a relationship within the subroutine as a function of the number of launches and the number of years in the program. Included in this category is launch vehicle operations, launch site support for spacecraft, and recovery cost of the logistics spacecraft.

Expendables cost is constant at $904,000 for each cargo module launched. Ground operations include the costs of mission planning and analysis, mission control, manned space flight network operations, and flight crew operations.

The program terminates with the summation and printout of total program costs.

13.2.1.3 Cost Arrays - The purpose of using cost arrays in the cost subroutine was to provide a simple method for costing a complex space station program. By means of the cost array approach, space station costs for a limited set of conditions were generated through the application of the Spacecraft Cost Model and the Launch Vehicle Cost Model. In addition to the space station costs, the development and hardware costs for the logistics spacecraft were determined through the use of these models. During the programming of the cost subroutine, the cost values were stored in cost arrays in a manner so that specific values would be subject to the user's instructions.

The costs of the MORL space station for the baseline 28.5 to 50-degree, polar, and synchronous orbit were built into the cost subroutine. The cost data were computed through the use of the Spacecraft Cost Model. In Table 13-1, the R&D costs of the space station are detailed along with the costs of ground support equipment design, development, manufacturing and installation. The R&D costs reflected include the cost of design and development engineering, tooling, and boilerplate hardware for each subsystem of the space station. The space station hardware cost category includes the cost of sustaining engineering. Reflected in the hardware category is the cost of one operational space station and one backup unit. The policy for handling the PU-238 fuel cost of the electrical power subsystem was adopted directly from the MORL Phase IIB study.

The initial operations cost data include launch site support, computed from the Spacecraft Cost Model, and initial launch vehicle hardware and operations cost computed from the Launch Vehicle Cost Model. It was assumed that one additional tracking and communications

Table 13-1 MORL R&D COSTS

Cost ($1000)

	Baseline	Polar	Synchronous
Structure			
RD&E	170,552	191,363	262,198
BPH	15,794	15,906	17,168
Environmental Control			
RD&E	129,350	129,350	129,350
TOOL	2,498	2,498	2,498
BPH	13,817	13,817	13,817
Crew Systems			
RD&E	13,683	13,683	13,683
TOOL	511	511	511
BPH	2,687	2,687	2,687
Stabilization and Control			
RD&E	85,284	89,195	192,622
TOOL	2,185	2,495	5,129
BPH	37,770	39,276	84,695
Reaction Control			
RD&E	16,075	16,075	16,075
TOOL	1,811	1,811	1,811
BPH	4,854	4,854	4,854
Electrical Power			
RD&E	31,904	31,904	31,904
BPH	16,340	16,340	16,340
Communications			
RD&E	14,076	14,115	14,397
TOOL	210	211	225
BPH	9,314	9,322	9,939
Instrumentation			
RD&E	4,750	5,070	3,656
TOOL	182	195	141
Subtotal	**573,659**	**600,689**	**828,710**
TGSE R&D	**405,106**	**405,106**	**405,106**
TOTAL	**972,765**	**1,005,795**	**1,233,816**

station would be required for the 28.5 to 50-degree orbit (above those now available) and two new tracking and communication facilities would be required for the polar orbit.

The logistics spacecraft costs consist of a command module and one of the configurations of the four multimission modules, i.e., cargo (LMMM1), experiments (LMMM2), retrofit (LMMM3), or excursion (LMMM4). The R&D costs for the command module and each multimission module were computed by the Spacecraft Cost Model (see Table 13-2). The R&D cost for each version of the logistics spacecraft reflects the cost of one unmanned and two manned test flights. Ground test and spares costs were assumed negligible. R&D costs for the command module were computed for only those subsystems that were newly developed. It was estimated that the R&D costs for modifying the environmental control and communications subsystem would be 5% of the original Apollo subsystem R&D costs. The propulsion R&D cost for the command module was computed from a cost estimating relationship developed for solid propulsion motors. A new relationship for the cost of the battery electrical power system was developed.

The R&D costs for the four configurations of the multimission module are itemized in Table 13-2. The cost data for the experiments configuration represent an incremental increase relative to the cargo module. This increase is due to an estimated 2% addition

Table 13-2 LOGISTIC VEHICLE R&D COSTS

Cost ($1000)

CONFIGURATION	COMMAND MODULE	CARGO MODULE LMMM1	EXPERIMENTS MODULE LMMM2	RETROFIT MODULE LMMM3	EXCURSION MODULE LMMM4
SUBSYSTEM COSTS					
Structure	52,263	70,006	70,524	71,829	70,006
Propulsion	8,544	0	0	0	0
Environmental Control	9,602	0	15,359	16,162	0
Crew Systems	4,956	0	12,028	12,028	0
Stabilization	17,220	19,216	19,228	19,248	19,216
Reaction Control	42,965	19,773	19,77[illegible]	19,773	19,773
Nav. & Guidance	31,413	0	0	0	0
Electrical Power	2,697	0	0	0	0
Communications	18,281	0	0	0	0
Instrumentation	9,734	0	19,544	19,588	0
Launch Escape	9,187	0	0	0	0
Recovery	4,632	0	0	0	0
Adapter	0	4,909	4,909	4,909	4,909
MODULAR LEVEL COSTS					
Non-Flight Test Recurring	71,589	24,698	56,406	56,293	24,698
Flight Test Recurring	24,939	24,939	24,939	24,939	24,939
SPACECRAFT LEVEL COSTS					
GSE	0	0	0	0	0
Flight Crew Ops	0	0	0	0	0
TOTAL	308,021	163,540	242,710	244,769	163,540

*** From Spacecraft Cost Model Run**

in weight, reflecting the addition of a crew and environmental control system. The cost data for the retrofit module also reflect the increment in its cost relative to the cargo version. This increase is due to an estimated 5% addition to the weight of the cargo version, since the retrofit module may have environmental control system computers. The cost data for the excursion module were estimated to be the same as those of the cargo version since the addition of fuel cells requires no additional R&D costs.

The cost data for the first production unit of each version of the spacecraft is shown in Table 13-3. Each version of the spacecraft consists of the command module and one of the four configurations of the multimission module. The costs were generated by the Spacecraft Cost Model.

The costs of the Saturn IB and Saturn V were computed by the Launch Vehicle Cost Model. The cost array for these vehicles is shown in Table 13-4. The hardware cost includes actual production plus sustaining tooling costs. The costs for the Saturn IB represent the costs of launching the space station and logistics spacecraft for the baseline 28.5 to 50-degree inclination cases. The costs for the Saturn V launch vehicle are applicable to the polar and synchronous orbits.

Table 13-3 ARRAY OF FIRST UNIT PRODUCTION COSTS AND LEARNING ASSUMPTIONS

	LEARNING CURVE	Cost ($1000 Units) Spacecraft Configuration COMMAND MODULE	LMMM1	LMMM2	LMMM3	LMMM4
Structure	.16912	24,404	11,537	11,641	11,833	0
Propulsion	.12030	208	0	0	0	0
Environmental Control	.07400	2,110	0	602	836	0
Crew System	.15200	1,877	0	1,680	1,680	0
Stabilization & Control	.20091	6,706	6,647	6,649	6,652	0
Reaction Control	.16912	7,530	7,580	7,580	7,580	0
Guidance & Nav.	.07400	11,599	0	0	0	0
Electrical Power	.15200	900	0	0	0	0
Communications	.15200	7,151	0	0	0	0
Instrumentation	.18442	4,291	0	6,197	6,197	0
Launch Escape	.12442	4,101	0	0	0	0
Recovery	.15200	1,792	0	0	0	0
Adapters	.08927	0	1,410	1,410	1,410	0

Table 13-4 ARRAY OF FIRST UNIT PRODUCTION COSTS AND LEARNING ASSUMPTIONS

Cost ($1000)

SPACECRAFT CONFIGURATION	STRUCTURE	PROPULSION	ASTRIONICS
Saturn IB			
SI	11,509	300(8)*	0
SI-IU	0	0	2,500
SIV-B	9,550	1,710(1)*	0
Saturn V			
SIC	19,818	3,248(5)*	0
SII	14,713	1,710(6)*	0
SIVB	9,550	0	0
SV-IU	2,696	0	489

* Number of Propulsion Systems on Stage = n

Hardware cost is computed by a learning curve method called the modified-Wright theory. The learning exponents are those derived by Booz-Allen Applied Research, Inc., for the Spacecraft Cost Model and are used in this subroutine as an average of those derived between manufacturing and sustaining engineering since their separate values are within a very small range. The computation occurs at the subsystem level, and the corresponding subsystem on each module would have the same learning curve. The launch vehicle learning curve reflects the improvements in manufacturing and sustaining tooling.

Operations cost is computed within the cost subroutine. The cost is separated into launch operations and ground operations cost. The cost of launch operations is determined by the launch rate along with pad and complex related costs from the LVCM. The Spacecraft Cost Model provided the cost of recovery operations and launch site support. Each launch vehicle has a different equation which is a function of the number of logistics missions and the number of years of the program. The cost of ground operations consists of mission planning and analysis, mission control, and flight crew operations cost. The cost subroutine uses an equation to compute ground operations cost as a function of the number of years in the program.

13.2.2 Resource Profiles

Within the evaluation routine the space station mission plan is described by means of (1) the logistics launch profile, (2) the logistics payload compositions, and (3) the scheduled allocations of critical resources.

13.2.2.1 Logistics - The summary mission evaluation parameters obtained from the logistics routine include (1) the program launch profile, (2) a summary of the cargo and crew to be delivered to the station, and (3) an a priori assessment of the probability distribution of logistics vehicles required. The logistics evaluation data are itemized in Table 13-5.

The mission launch profiles indicate the launch numbers, the mission day of each planned launch (counting from the laboratory launch date as day zero), and the number of crewmen to be delivered with each launch. The cargo to be delivered is comprised of four categories: (1) experimental equipment, (2) fixed equipment, (3) expendables, and (4) excess capacity. The total cargo to be delivered represents the requirements of each category, as well as any excess capacity, for the entire planned program.

A comparison of the confidence level versus vehicle requirements indicates the probability β_i that N_i launch vehicles will be sufficient to provide the N successful launches required as shown in the program launch profile. The required confidence levels

Table 13-5 LOGISTICS EVALUATION

Mission Duration = X Days

PROGRAM LAUNCH PROFILE

Launch Number	0	1	2	3	-	-	-	N
Mission Day of Launch	0	X	X	X	-	-	-	X
Number of Crewmen Delivered	0	X	X	X	-	-	-	X

Number of Logistics Vehicles Required	X
Number of Pure Cargo Vehicles Required	X
Number of Crewmen Delivered to Laboratory	X

Confidence Level Required	Confidence Level Actual	Number of Vehicles Required
α_1	B_1	N_1
.	.	.
.	.	.
.	.	.
α_K	B_K	N_K

SUMMARY OF CARGO DELIVERED

Cargo Category	Total Weight	Total Volume	Percent Weight	Percent Volume
Experimental Equipment	X	X	X	X
Fixed Equipment	X	X	X	X
Expendables	X	X	X	X
Excess Capacity	X	X	X	X
Total Payload Capability	XX	XX	100%	100%

are input parameters. The actual number of launches required and the effects of launch failures upon the mission plan are factors to be analyzed in the Simulation Mode.

13.2.2.2 Resource Allocations - Efficient utilization of critical resources is the primary objective of the scheduling routine of the Space Station Model. The evaluation routine reflects a summary of the critical resources allocated in the scheduling routine. This summary includes the planned utilization of man-hours and electrical energy.

The description of the planned man-hour utilization is summarized as (1) the total man-hours allocated to each work classification, summed for all crewmen over the entire planned program, and (2) the man-hours allocated to each work classification by each crew man. In this summary the work classifications are combined into four categories: personal requirements, station keeping tasks, experimental program, and unscheduled time (see Table 13-6).

The total program allocations indicate the relative man-hour expense for each of the work classifications. The summary of the total program allocations represents the planned efforts in each category, as well as the unscheduled time, for the entire program.

Table 13-6 MAN-HOUR ALLOCATIONS

TOTAL PROGRAM ALLOCATIONS

Classification	Total Hours	Percent	Average Hours/Day
Personal Requirements	X	X	X
Station Keeping Tasks	X	X	X
Experimental Program	X	X	X
Unscheduled Hours	X	X	X
Total Hours Available	XXX	100%	X

AVERAGE DAILY REQUIREMENTS (PERCENT) BY CREWMEN

Crewman	Personal Requirements	Station Keeping Tasks	Experimental Program	Unscheduled Hours
1	X	X	X	X
2	X	X	X	X
3	X	X	X	X
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.

The electrical energy requirements for the planned station operations and the experimental program are summarized in the format shown in Table 13-7.

Table 13-7 ELECTRICAL ENERGY PROFILES

Classification	Total A.C.	Total D.C.	Average Energy Used per Day A.C.	Average Energy Used per Day D.C.
Station Keeping Tasks	X	X	X	X
Experimental Program	X	X	X	X
Unscheduled	X	X	X	X
Total	XX	XX		

13.2.3 Effectiveness Measures

The effectiveness measures evolved in the evaluation routine are used to analyze the program developed in the other routines of the Space Station Model. These measures also provide a means for comparing the different missions generated by repeated use of the Planning Mode of the Space Station Model.

Two sets of effectiveness measures are presented: (1) a set of parameters for measuring the gross efficiencies of the resource utilizations and (2) a set of parameters for measuring cost effectiveness in terms of critical resources. The effectiveness measures are enumerated in Table 13-8.

Table 13-8 EFFECTIVENESS MEASURES

EFFICIENCIES	
% of cargo weight utilization	X
% of cargo volume utilization	X
% of laboratory man-hours which have been scheduled	
% of experimental man-hours provided	X
% of experimental man-hours provided which have been scheduled	
% of electrical energy utilized A.C.	X
D.C.	X
COST/EFFECTIVENESS	
\$ per pound delivered to laboratory	X
\$ per pound of the experimental program	X
\$ per laboratory man-hour	X
\$ per experimental man-hour provided	X
\$ per scheduled experimental man-hour	X
SPECIAL	
Versatility Index ($0 \leq V \leq 1$)	X
Growth Index G1 G1 (LBS) = 1 (HR)	X
Growth Index G2 G2 (LBS Utilized) = 1 (LB Utilized)	X

The efficiency parameters, indicated in Table 13-8, reflect the percent utilization of the mission's capabilities. A description of each of these parameters follows:

<u>% of Cargo Weight Utilization</u> - This parameter reflects the percent of the total program's cargo capacity which has been scheduled for the delivery of experimental equipment, fixed equipment and expendables.

% of Cargo Volume Utilization - Same as above; only the parameter being measured is volume.

% of Laboratory Man-hours Which Have Been Scheduled - This parameter indicates the percent of the total man-hours (at the space station) which have been scheduled for the performance of personal requirements, station keeping tasks, and accomplishments of the experimental program.

% of Experimental Man-Hours Provided - This parameter indicates the percent of the total man-hours which are available at the station for use in the experimental program after the personal requirements and the station keeping tasks requirements are satisfied.

% of Experimental Man-Hours Provided Which Have Been Scheduled - This parameter reflects the percent of the man-hours (available for experiments) that have been scheduled.

% of Electrical Energy Utilized - This parameter indicates the percent of the total electrical energy capacity which is utilized.

The cost/effectiveness parameters (Table 13-8) are computed as the ratio of total program cost to gross amounts of the various critical resources.

$ Per Pound Delivered to Laboratory - This parameter is the ratio of total program cost to the weight of the experimental equipment, fixed equipment, and expendables delivered to the space station.

$ Per Pound of the Experimental Program - This parameter is the ratio of the total program cost to the weight of the experimental equipment delivered to the space station.

$ Per Laboratory Man-Hour - This parameter is the ratio of the total program cost to the total number of man-hours provided at the laboratory

$ Per Experimental Man-Hour Provided - This parameter is the ratio of total program cost to the number of laboratory man-hours available for accomplishment of the experimental program.

$ Per Scheduled Experimental Man-Hour - This parameter is the ratio of total program cost to the man-hours available for use in the experimental program, which have actually been scheduled. That is, the $/hr based on the scheduled experimental man-hours.

Versatility Index - The versatility index, V, is computed as

$$V = 1 - (A'/A)(B'/B)$$

where

- A = total cargo weight capacity of the logistics profile
- A' = weight actually delivered to the laboratory
- B = total number of man-hours at the laboratory
- B' = the number of man-hours which have been scheduled for some activity.

The versatility index is a measure of the unscheduled critical resources. V equals zero implies that all of both resources have been scheduled to capacity. V equals 1 implies that none of one or both of these resources has been scheduled.

Growth Index G1 - The growth index, G1, is computed as

$$G1 = (B/A)$$

where A and B are defined as above. G1 indicates the relationship between the weight delivering capability of the logistics profile and the man-hours provided at the laboratory.

Growth Index G2 - The growth index, G2, is computed as

$$G2 = (B'/A')$$

where A' and B' are defined as above. G2 indicates the relationship between the actual cargo capacity which was used and the man-hours which have been scheduled.

The discussion of the effectiveness measures has been confined to a precise description of how each index is calculated. Specific implications or explanations of the meaning of the effectiveness indexes have not been attempted. Obviously each index has multiple implications regarding the evaluation of any mission, and a delineation of specific index implications would place an unnecessary restriction upon the use of these indexes in mission evaluation.

13.3 Simulation Mode Evaluation Routine

The Simulation Mode evaluation output is a summary of the actual requirements incurred and accomplishments obtained when a segment of the planned mission is simulated. The simulation segment is from crew arrival to crew arrival. Thus, to accomplish a simulation of an extended mission, a sequence of segments would be considered.

The objective of the Simulation Mode is to provide the capability for analyzing the effects of probabilistic events upon a space station mission. Consequently, in the evaluation routine of the Simulation Mode, emphasis is placed on presenting the effects of the probabilistic events upon the planned mission in terms of changes in resource requirements and accomplishments. The output of the evaluation routine is a summary of the effects of the probabilistic events. In addition, intermediate printouts are provided at the time of each event occurrence. The intermediate printouts provide a description of any random event which has occurred and its effects upon station operations.

The Simulation Mode evaluation is printed out in sections containing (1) man-hour utilization, (2) experimental program, and (3) station keeping task data.

13.3.1 Man-Hour Utilization Summary

The description of how the man-hours are utilized in the program simulation is summarized in Table 13-9. For summary purposes, the work classifications are combined into four categories: (1) personal requirements, (2) station keeping tasks, (3) experimental program, and (4) the time required for the processing of contingency tasks.

Table 13-9 MAN-HOUR UTILIZATION SUMMARY

Interval XX to XX

Classification	Total Hours	Percent	Average Hrs/Day
Station Keeping Tasks	XX	XX	XX
Experimental Program	XX	XX	XX
Unscheduled Hours	XX	XX	XX
Contingency Tasks (not including overtime)	XX	XX	XX

Personal requirements of XX.X hours per day include 8.0 hours sleep. The actual amount of sleep obtained during days on which contingencies occur can be determined by subtracting the number of overtime hours worked from 8.0

13.3.2 Experimental Program and Station Keeping Tasks Summary

The summary description of the experimental program and station keeping task interruptions due to occurrence of probablistic events is presented in Table 13-10. The summary includes (1) the number of experiments and station keeping tasks interrupted, (2) the number of interrupted experiments which result in a data loss, and (3) the number of experiments which have not been rescheduled since their interruptions.

Table 13-10 EXPERIMENT SUMMARY

Interval XX to XX

Total Number of Experiments Interrupted	XX
Number Which Cause Loss of Data	XX
Number Which Cause No Loss of Data	XX
Number Which Have Been Rescheduled	XX
Number Which Have Not Been Rescheduled	XX

STATION KEEPING TASKS SUMMARY

Total Number of Station Keeping Tasks Interrupted	XXX

13.3.3 Experimental Program and Station Keeping Tasks Status Report

The final printout of the evaluation routine, Simulation Mode, is a status report of the experiment program and station keeping tasks at the end of the interval being simulated. This status report includes the event (i.e., experiment or station keeping task) identification, crewman assigned to the event, hours worked, the event start date, the number of days the event was interrupted during the interval, the last day on which the event was restarted and a current status code for each event. The printout format of this status report is depicted in Table 13-11.

Table 13-11 EXPERIMENTAL PROGRAM AND STATION KEEPING TASKS EVALUATION

EXPERIMENT STATUS REPORT FOR INTERVAL XX TO XX

Event	Crewman Assigned to this Event NM(1)	NM(2)	NM(3)	NM(4)	NM(5)	NM(6)	Hours WKD	SM1	SM2	SM3	Status Code
1	X	X	X	X	X	X	X	X	X	X	X
2	X	X	X	X	X	X	X	X	X	X	X
3	X	X	X	X	X	X	X	X	X	X	X
.	.	.	.	.	.	.					
.	.	.	.	.	.	.					
.	.	.	.	.	.	.					

STATION KEEPING TASKS STATUS REPORT FOR INTERVAL XX TO XX

Event	Crewman Assigned to this Event NM(1)	NM(2)	NM(3)	NM(4)	NM(5)	NM(6)	Hours WKD	SM1	SM2	SM3	Status Code
1	X	X	X	X	X	X	X	X		X	X
2	X	X	X	X	X	X	X	X	[illegible]	X	X
3	X	X	X	X	X	X	X	X	X	X	X
.											
.											
.											

Legend

SM1	The Scheduled Start Day for This Event
SM2	Total Number of Days Interrupted to Date in This Interval
SM3	Last Day on Which Event Was Restarted

Status Code

=1	Event Is In-Progress and Not Currently Interrupted
=2	Event Is In-Progress but Currently Interrupted
=3	Event Has Been Completed
=4	Event Has Been Scheduled but Has Not Yet Been Started
=5	Event Has Never Been Scheduled

14.0 EXAMPLES OF MODEL RESULTS

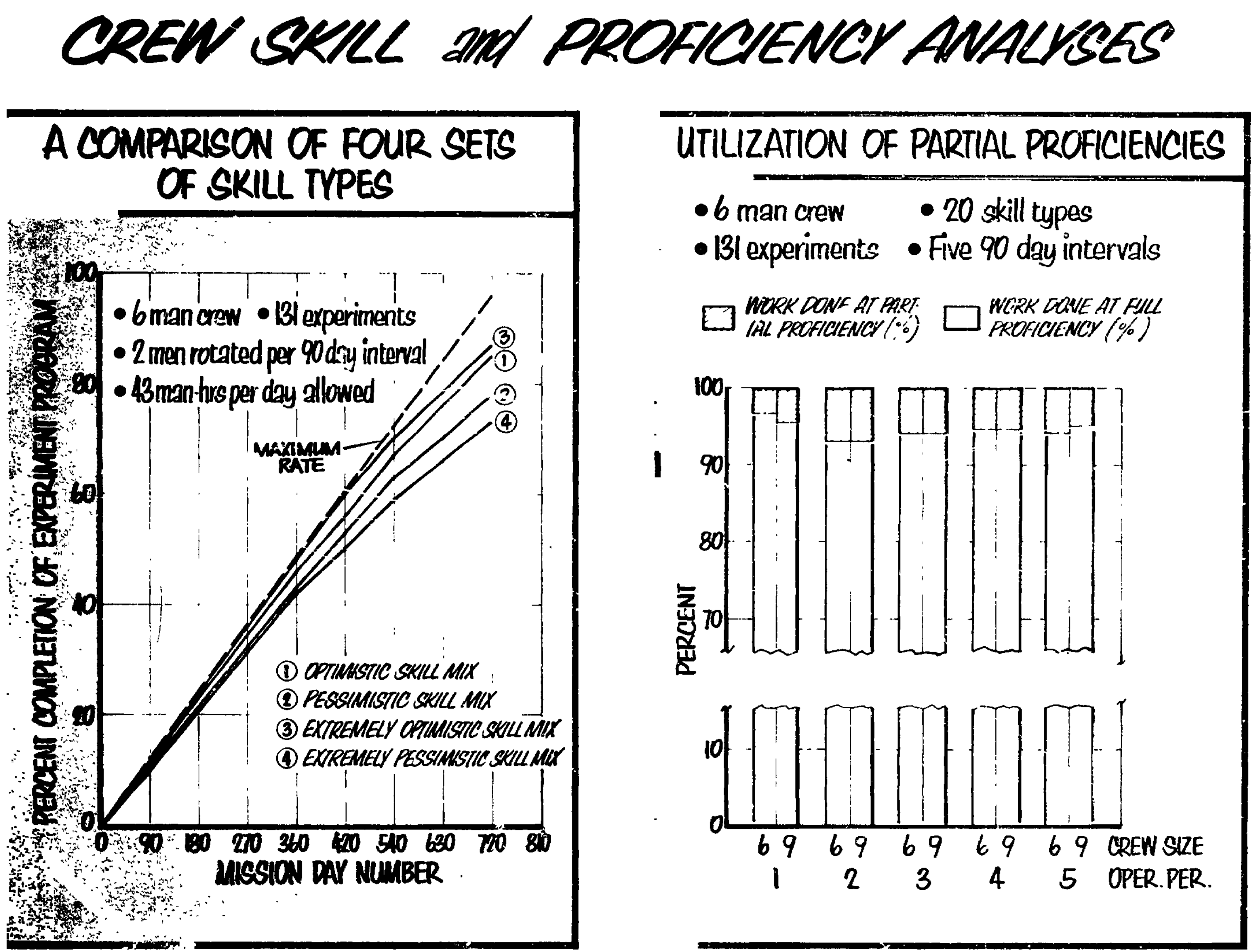
14.1 Introduction

Some of the results obtained from check-out problems and specific case studies are presented in this section to demonstrate the specific types of results that can be obtained from use of the models. The results shown are indicative of the type of results that can be obtained, but represent only a small portion of the spectrum of possible model applications.

14.2 Typical Model Studies

14.2.1 Crew Skill and Proficiency Analysis

Four different sets of skill mixes were processed through the Preliminary Requirements Model to provide an example of the efficiency that can be obtained with varying levels of skill. The results are depicted in Figure 14-1. The optimistic, pessimistic skill mixes consist of 20 primary skill types each. The extremely optimistic skill mix consists of only four skill types: a biomedical scientist, an engineer, a physical scientist, and an earth scientist. Each of the four skill types provides full proficiency in all related skills. The extremely pessimistic skill mix utilizes 20 skill types with proficiency only in the primary skill. The maximum rate of completion represents the optimum assignment of experiments, i.e., 43 man-hours are worked each day.



CREW SKILL and PROFICIENCY ANALYSES
A COMPARISON OF FOUR SETS OF SKILL TYPES
• 6 man crew • 131 experiments
• 2 men rotated per 90 day interval
• 43 man-hrs per day allowed
MAXIMUM RATE
① OPTIMISTIC SKILL MIX
② PESSIMISTIC SKILL MIX
③ EXTREMELY OPTIMISTIC SKILL MIX
④ EXTREMELY PESSIMISTIC SKILL MIX
PERCENT COMPLETION OF EXPERIMENT PROGRAM
0
20
40
60
80
100
0 90 180 270 360 450 540 630 720 810
MISSION DAY NUMBER
UTILIZATION OF PARTIAL PROFICIENCIES
• 6 man crew
• 20 skill types
• 131 experiments
• Five 90 day intervals
WORK DONE AT PARTIAL PROFICIENCY (%)
WORK DONE AT FULL PROFICIENCY (%)
PERCENT
0
10
70
80
90
100
6 9 6 9 6 9 6 9 6 9 CREW SIZE
1 2 3 4 5 OPER. PER.

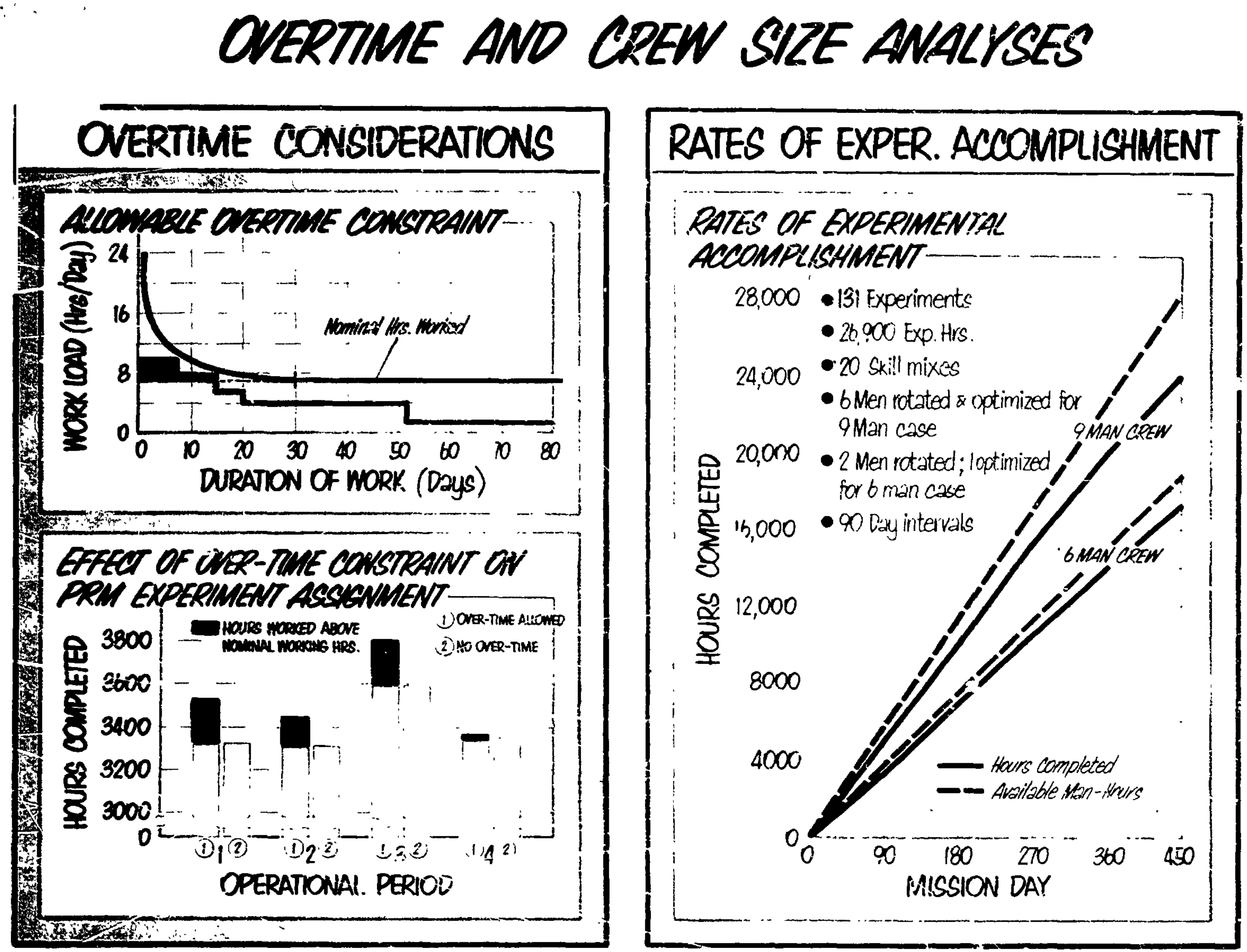
Figure 14-1

The crew proficiency levels were determined from an analysis of questionnaires completed by specialists at Langley Research Center and General Dynamics. Whenever two significant proficiency levels existed for a given skill mix, the highest level was selected for the optimistic skill mix and the lowest level was used for the pessimistic skill mix.

A comparison of the experiment hours performed at full and partial proficiencies for a six-man and nine-man crew is depicted on the right side of Figure 14-1. The percent of work done at partial proficiency is found by determining the ratio of the difference between the total hours worked and the total experiment hours completed to the total number of experiment hours. It can be seen that, for either crew size, a relatively small portion of the total experimental work (approximately 5 percent) was assigned to crewmen with partial proficiency in the required skills.

14.2.2 Overtime and Crew Size Analyses

The PRM permits the assignment of work to crewmen in excess of their normal work loads for short periods of time. The method used in assigning this additional work is illustrated by the constraint relationship shown in Figure 14-2. If the addition of an experiment to the existing work load profile causes the resulting profile to penetrate the curve shown in this figure, the experiment will be rejected; if not, it will be assigned. The parameters



OVERTIME AND CREW SIZE ANALYSES
OVERTIME CONSIDERATIONS
ALLOWABLE OVERTIME CONSTRAINT
WORK LOAD (Hrs/Day)
24
16
8
0
0 10 20 30 40 50 60 70 80
DURATION OF WORK (Days)
Nominal Hrs. Worked
EFFECT OF OVER-TIME CONSTRAINT ON PRM EXPERIMENT ASSIGNMENT
HOURS WORKED ABOVE NOMINAL WORKING HRS.
1) OVER-TIME ALLOWED
2) NO OVER-TIME
HOURS COMPLETED
3800
3600
3400
3200
3000
0
OPERATIONAL PERIOD
RATES OF EXPER. ACCOMPLISHMENT
RATES OF EXPERIMENTAL ACCOMPLISHMENT
131 Experiments
26,900 Exp. Hrs.
20 Skill mixes
6 Men rotated & optimized for 9 Man case
2 Men rotated; optimized for 6 man case
90 Day intervals
HOURS COMPLETED
28,000
24,000
20,000
16,000
12,000
8000
4000
0
0 90 180 270 360 450
MISSION DAY
9 MAN CREW
6 MAN CREW
Hours Completed
Available Man-Hours

Figure 14-2

governing the shape of this curve are PRM inputs. The effects of this overtime constraint are illustrated in the lower graph. This graph reflects the hours of experimental work completed by a six-man crew during five 90-day operational periods both with and without overtime capability. It can be seen that the overtime allowance results in a fairly small increase (approximately 3 percent) in the total hours of experimental work accomplished.

A comparison of the hours of experimental work accomplished by a six and a nine man crew is shown on the right side of Figure 4-2. The dashed lines indicate the rate at which the man-hours become available (7 hours per day per crewman). In both cases, the work rate is uniform throughout the mission, and the utilization of available working hours appears acceptable.

14.2.3 Logistics Vehicle Utilization

The composition of the payloads delivered into orbit during a 464-day mission (requiring seven logistics launches) is shown in Figure 14-3. In the upper graph are shown the cumulative weights of expendable items (fuel, water, food, etc.) and experimental equipment delivered by the logistics vehicles, as well as the cumulative unused weight capacity of these vehicles. The fraction of the total capacity of each vehicle filled by the payload is illustrated in the lower graph of Figure 14-3.

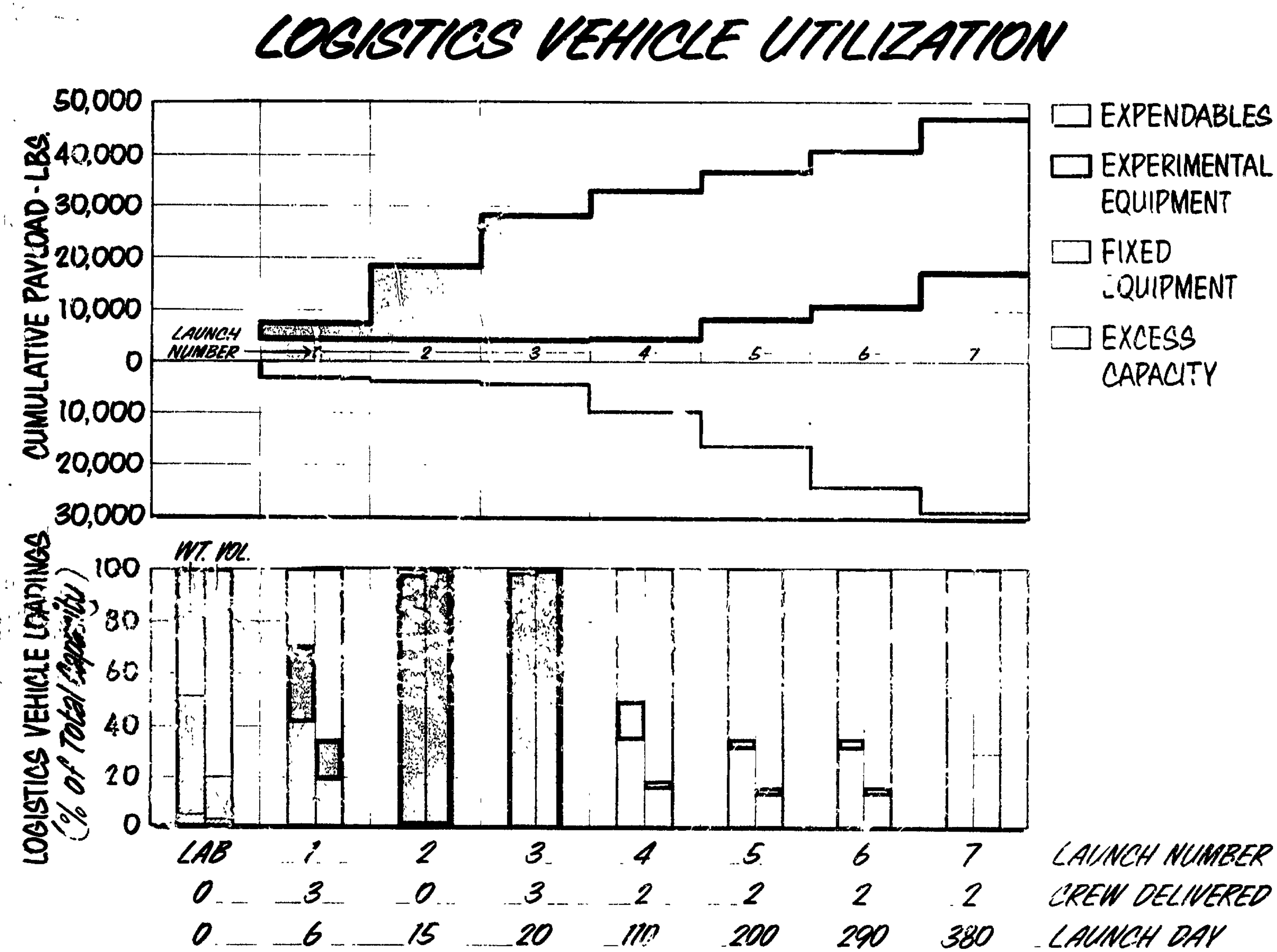

LOGISTICS VEHICLE UTILIZATION
CUMULATIVE PAYLOAD - LBS
50,000
40,000
30,000
20,000
10,000
0
10,000
20,000
30,000
LAUNCH NUMBER
1
2
3
4
5
6
7
EXPENDABLES
EXPERIMENTAL EQUIPMENT
FIXED EQUIPMENT
EXCESS CAPACITY
LOGISTICS VEHICLE LOADINGS
(% of Total Capacity)
WT. VOL.
100
80
60
40
20
0
LAB 1 2 3 4 5 6 7 LAUNCH NUMBER
0 3 0 3 2 2 2 2 CREW DELIVERED
0 6 15 20 110 200 290 380 LAUNCH DAY

Figure 14-3

With the exception of launches 2 and 3 which carry special experimental modules, the amounts of expendables and experimental equipment to be carried on each launch are computed in the Planning Mode. The amounts of expendables required for each launch are calculated from relationships incorporated into the model and are functions of mission parameters such as the number of days between launches and the number of crewmen on board. The amount of experimental equipment to be carried on each launch is determined by the scheduling of the experimental program, i.e., when the Planning Mode schedules an experiment to start on a given day, the equipment required by this experiment is placed on a launch arriving before that day. The relatively large amounts of experimental equipment required at the beginning of the mission is due to the initiation of long-term experiments during that period. The scheduling of the experiment program is not limited by the cargo-carrying capacity of the logistics modules since a considerable amount of excess capacity is always available.

14.2.4 Typical Crew Work Profiles Generated in the Planning Mode

The day-by-day work profiles for two crewmen whose assignments consist of both experiments and station operations and maintenance tasks are shown in Figure 14-4. The average work load shown on these charts represents the average number of hours worked each day by these men during the operational periods from which the samples were taken.

TYPICAL CREW WORK PROFILES GENERATED BY THE PLANNING MODE

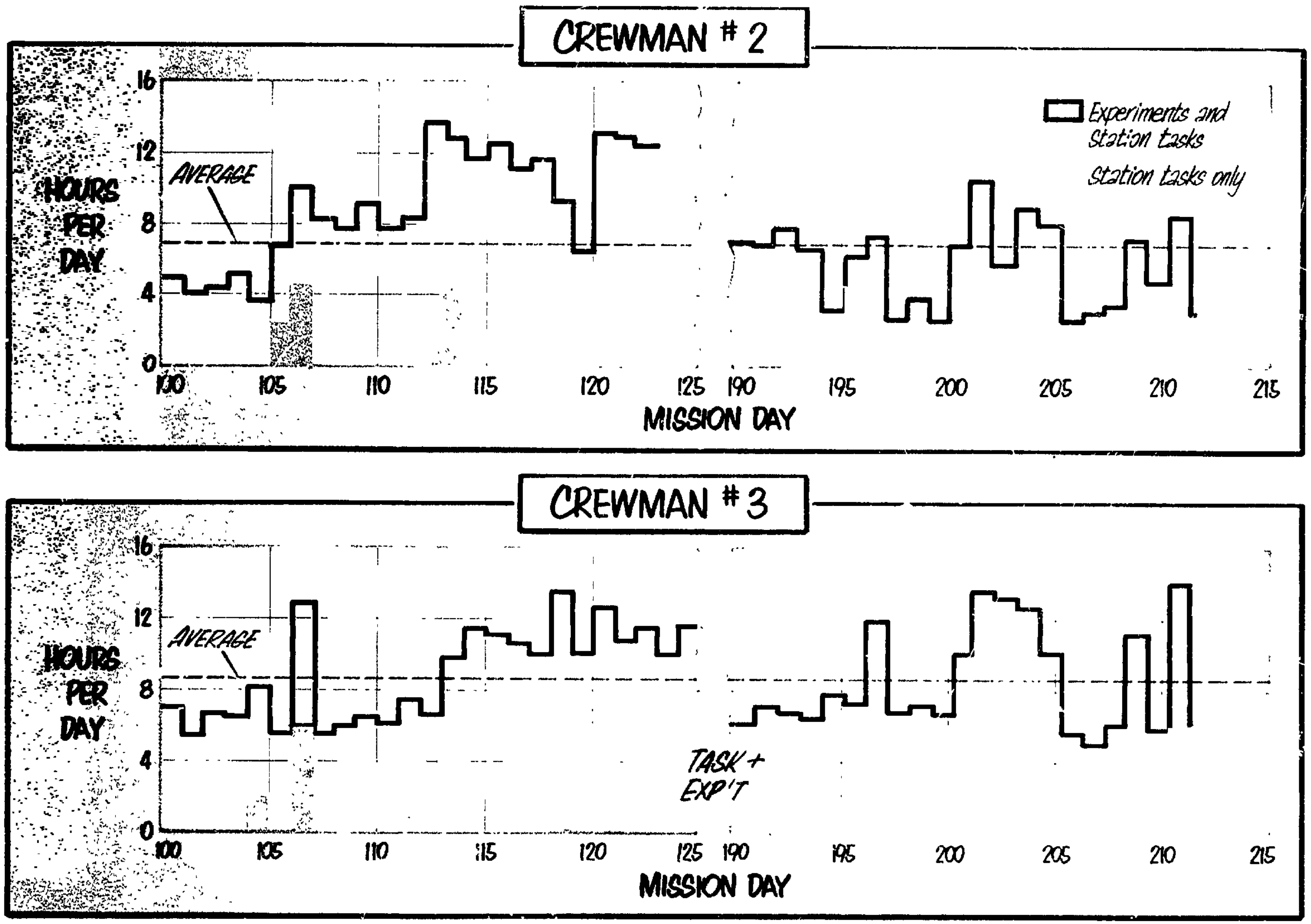


Figure 14-4

Although the average work load for either crewman is reasonable, there are three occasions when crewman 2 and two occasions when crewman 3 are assigned work loads in excess of 12 hours per day during the first 120 mission days.

14.2.5 Cost/Effectiveness Versus Mission Time

The Planning Mode provides a lengthy list of cost/effectiveness measures in its printout. An example of one of these measures and its application in the analysis of an experiment program is depicted in Figure 14-5.

One of the rather unique features of the Planning Mode is its ability to determine program cost based upon a confidence level logistics function objective. The requested points shown on the left side of Figure 14-5 are the values that must be achieved. The curve represents the actual values obtained. If no confidence level is specified, the minimum number of logistics launches is costed. This, of course, is the case when all launches are successful.

In the plot shown on the right side of Figure 14-5, the distribution of the cost per experiment hour over the mission duration is shown. This measure of cost/effectiveness is calculated by dividing the mission cost at the end of each logistics interval by the experiment hours either scheduled or provided to that point. As indicated by these data, there is a steady reduction in the cost per experiment hour as mission time progresses. However, the

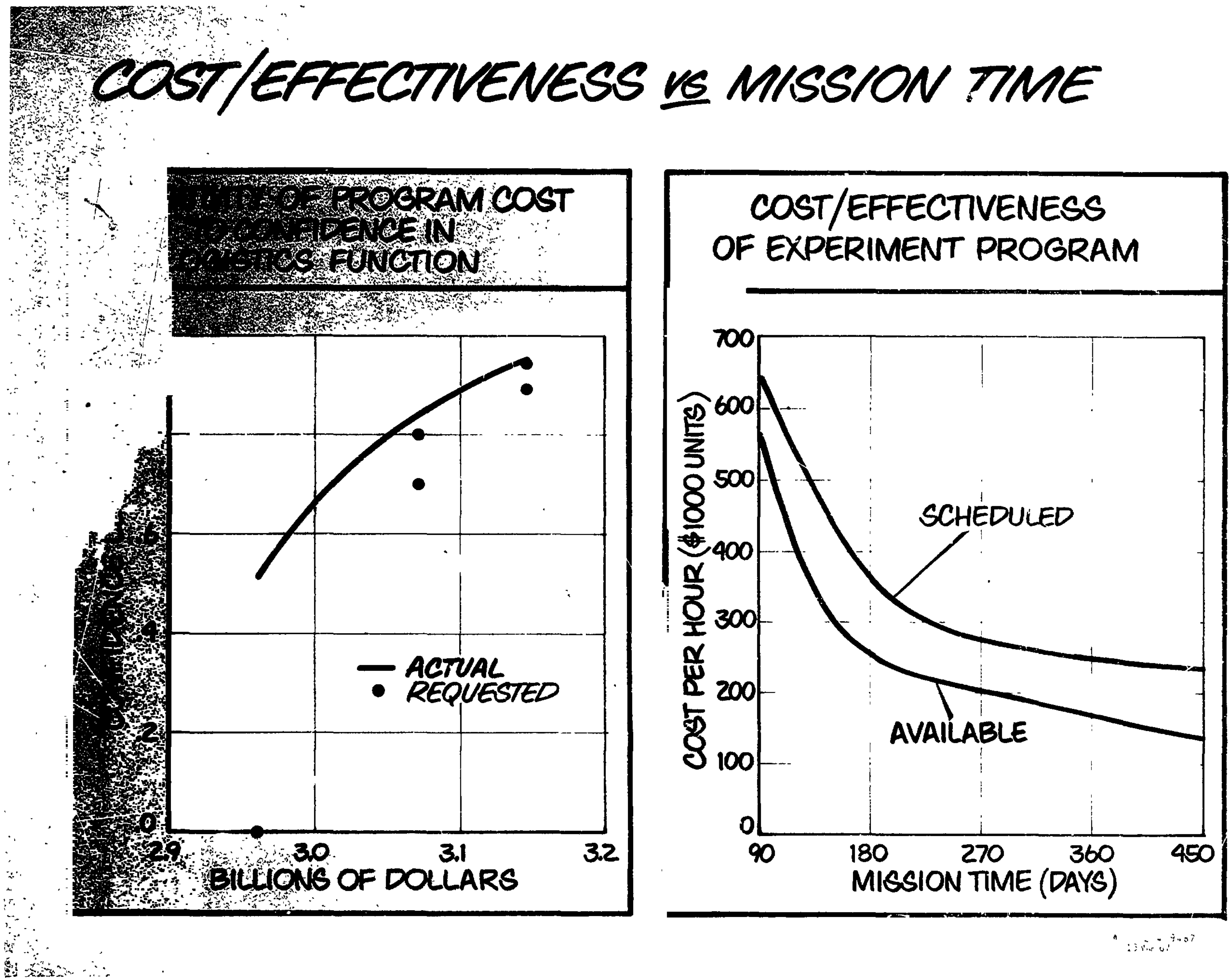

COST/EFFECTIVENESS VS MISSION TIME
PROGRAM COST
IN
FUNCTION
0
2
4
6
2.9
3.0
3.1
3.2
BILLIONS OF DOLLARS
ACTUAL
REQUESTED
COST/EFFECTIVENESS
OF EXPERIMENT PROGRAM
COST PER HOUR ($1000 UNITS)
0
100
200
300
400
500
600
700
90
180
270
360
450
MISSION TIME (DAYS)
SCHEDULED
AVAILABLE

Figure 14-5

depletion of the experiment's package might cause a reverse in the trend if mission time were to continue. Significant improvement in cost/effectiveness could be expected, as evidenced by the wide separation of the two plots, if significant improvement in scheduling of experiment hours could be achieved.

14.2.6 24-Hour Crew Profile

The typical activity time distributions for each of six crewmen in the initial and final operational periods are shown in Figure 14-6. The average for all crewmen during an operational period is also shown as the average man-day. This figure is shown to indicate the level of scheduling detail which is performed in the Planning Mode.

Each crew position is represented by an "average" day for the 90-day operational period. The different codings indicate the average number of hours per day utilized in a given activity. For this case, 10 hours spent in personal activities are noninterruptible; an additional 4 hours of personal time may be interrupted.

14.2.7 Electrical Power Utilization Analysis

The power consumed during a 464-day mission with a six-man crew is shown in Figure 14-7. AC and DC power usage rates are illustrated on the left side of the figure. The upper chart reflects the average power utilized by the experiment program during each

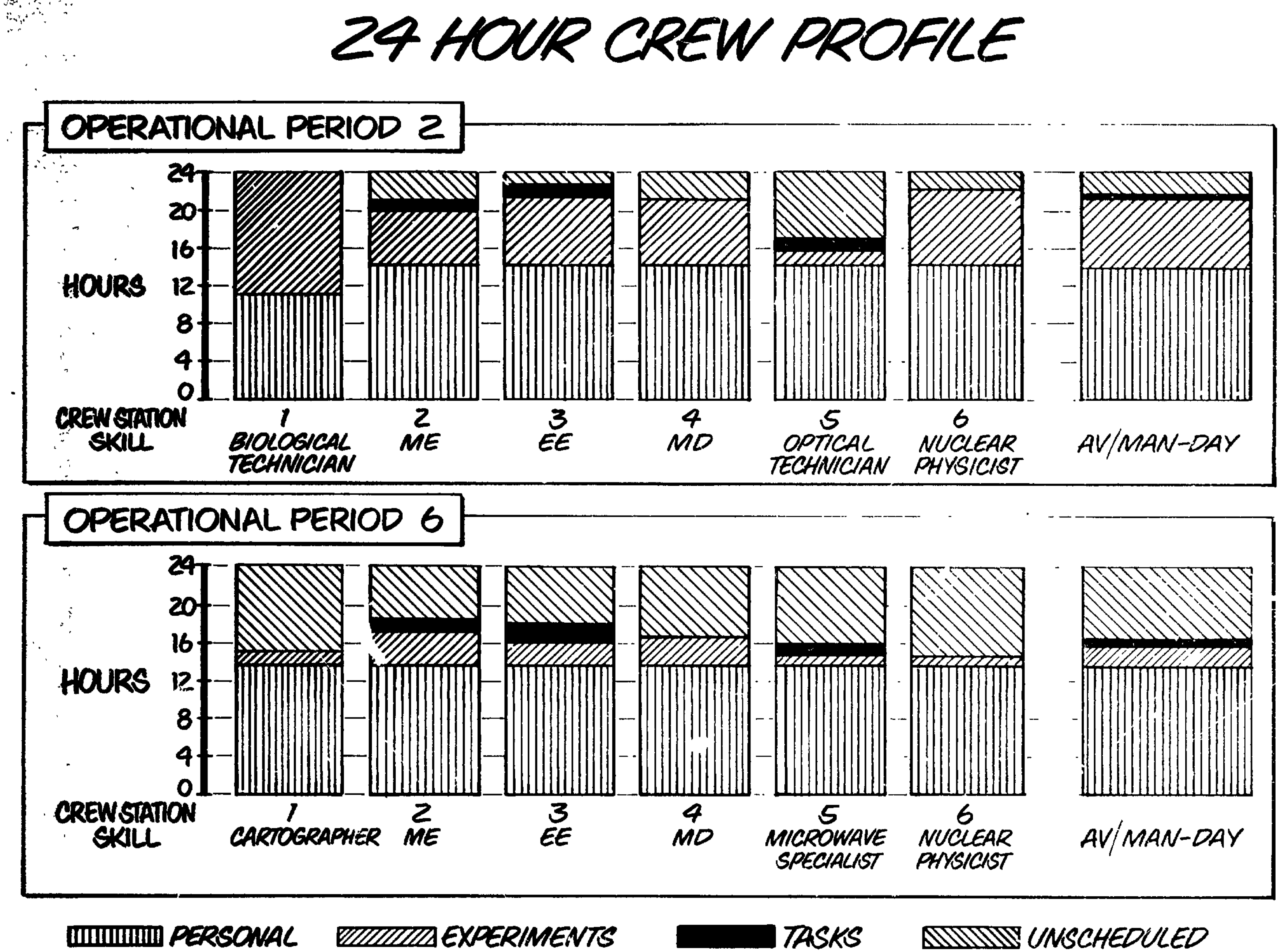
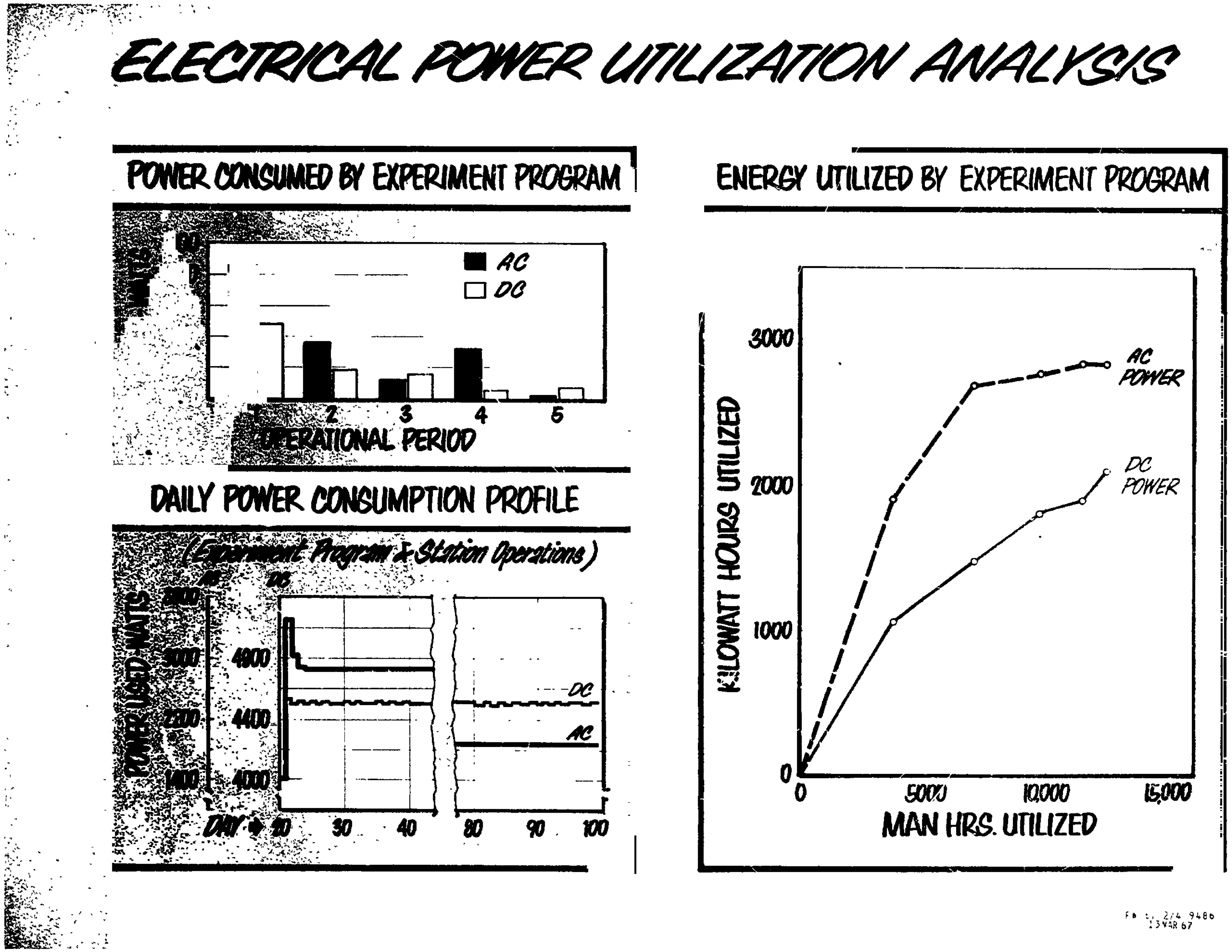

24 HOUR CREW PROFILE
OPERATIONAL PERIOD 2
HOURS
24
20
16
12
8
4
0
CREW STATION
SKILL
1 BIOLOGICAL TECHNICIAN
2 ME
3 EE
4 MD
5 OPTICAL TECHNICIAN
6 NUCLEAR PHYSICIST
AV/MAN-DAY
OPERATIONAL PERIOD 6
HOURS
24
20
16
12
8
4
0
CREW STATION
SKILL
1 CARTOGRAPHER
2 ME
3 EE
4 MD
5 MICROWAVE SPECIALIST
6 NUCLEAR PHYSICIST
AV/MAN-DAY
PERSONAL
EXPERIMENTS
TASKS
UNSCHEDULED

Figure 14-6



ELECTRICAL POWER UTILIZATION ANALYSIS
POWER CONSUMED BY EXPERIMENT PROGRAM
WATTS
AC
DC
1
2
3
4
5
OPERATIONAL PERIOD
DAILY POWER CONSUMPTION PROFILE
(Experiment Program & Station Operations)
POWER USED-WATTS
AC
DC
4800
4400
4000
1400
DAY
30
40
80
90
100
DC
AC
ENERGY UTILIZED BY EXPERIMENT PROGRAM
KILOWATT HOURS UTILIZED
3000
2000
1000
0
5000
10,000
15,000
MAN HRS. UTILIZED
AC POWER
DC POWER

Figure 14-7

operational period. The lower chart reflects a typical day-by-day power usage profile for the station.

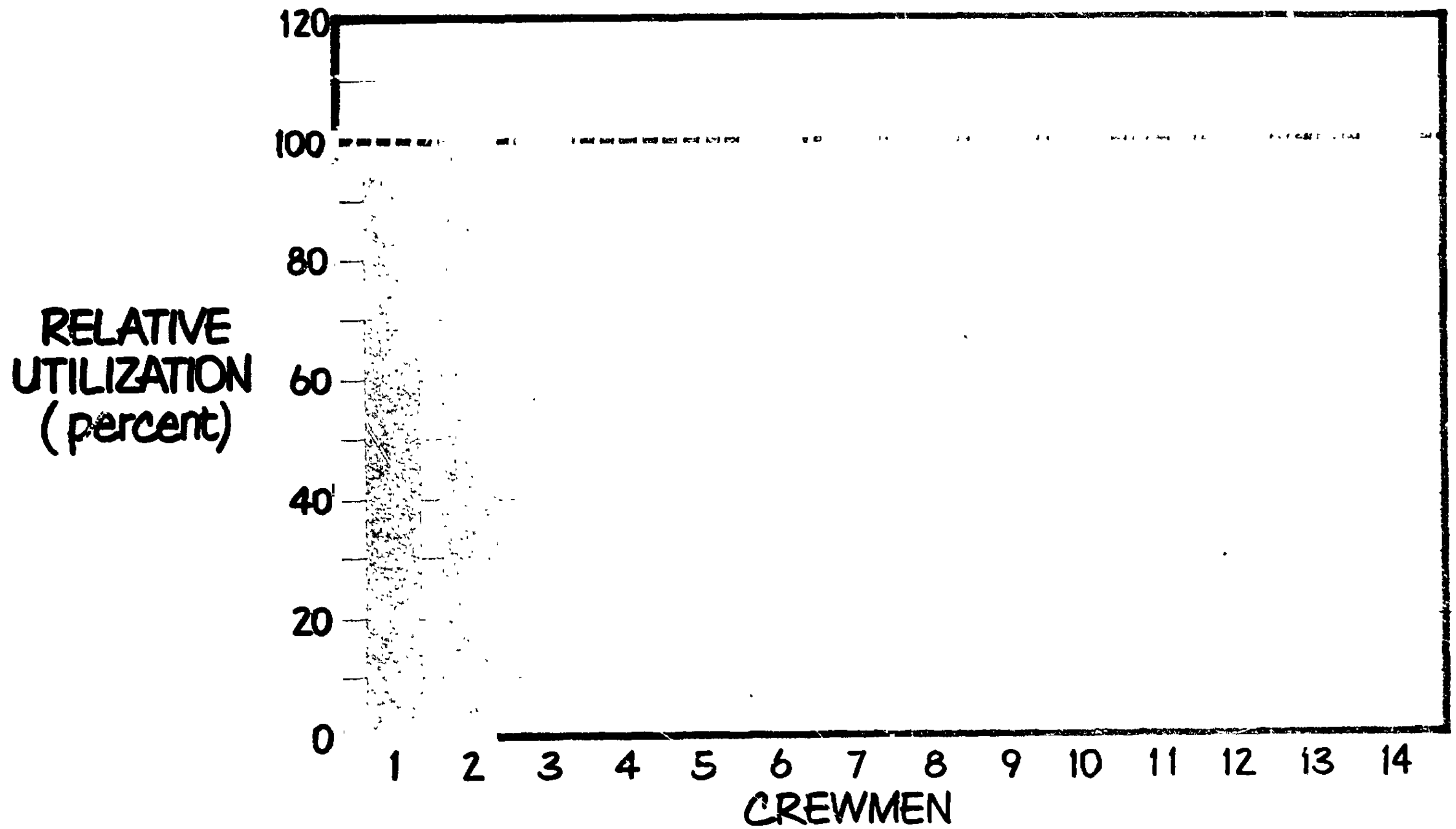
In the graph on the right, the electrical energy utilized is plotted as a function of the man-hours utilized by the experiment program. It can be seen that the DC energy is being consumed at approximately the same rate as the work assigned to the crew. On the other hand, the rate of AC energy consumption decreases relative to the rate at which the man-hours are utilized (indicating that the experiments requiring large amounts of AC power are scheduled early in the mission).

14.2.8 Relative Utilization of Crewmen

The relative utilization of the 14 crewmen participating in a 464-day mission is depicted in Figure 14-8. The relative utilization was calculated by determining the total number of hours worked on experiments and station operations tasks for each crewman and dividing this quantity by the average number of hours worked by a man during the time period that he was on board. This number provides a measure of the utilization of each crewman relative to other crewmen on board at the same time and thus, is useful in identifying those men whose work assignments are not in line with the rest of the crew. It can be seen in the case shown that the relative utilization of crewmen 4, 11, and 13 falls well below average (100 percent), indicating that the crew utilization for

RELATIVE UTILIZATION OF CREWMEN

• 6 MAN CREW • 464 DAY MISSION



$$\text{Relative Utilization} = \frac{\text{HOURS WORKED BY CREWMEN}}{\text{HOURS WORKED BY CREW DURING SAME TIME PERIOD}}$$

Figure 14-8

the entire mission could best be improved by modifying the work assignments of these three men.

14.2.9 Application of the Planning Mode to an Analysis of Rates of Accomplishment

The cases illustrated in Figure 14-9 were taken from two runs of the Planning Mode. The experiments package (consisting of 131 experiments) and the station operations tasks package (consisting of 30 tasks) were used in both runs. Crew size was 6 men in the first run and 9 men in the second.

After the first 90-day interval, the rate of experimental return declines progressively. This is due in part to the rapid exhaustion of small experiments, which tend to enhance scheduling efficiency, in the early phase of work.

Improvement in the percentage of the total experiment hours scheduled could be obtained by relaxing some of the rigid constraints presently imposed on the experiment package and recognized by the Planning Mode. For example, some long experiments, which were not scheduled because they could not be completed during the mission, might provide partial information if they were scheduled. These experiments may be scheduled by changing the experiment length descriptor from fixed time to mission duration. There are numerous other means, of course, of relaxing the rigidity of this experiment package.

APPLICATION OF THE PLANNING MODE TO AN ANALYSIS OF RATES OF ACCOMPLISHMENT

- 131 EXPERIMENTS
- 30 STA. OPERATION TASKS
- 26,900 MAN-HOURS, EXPERIMENTS
- 4800 MAN-HOURS STATION OPERATIONS

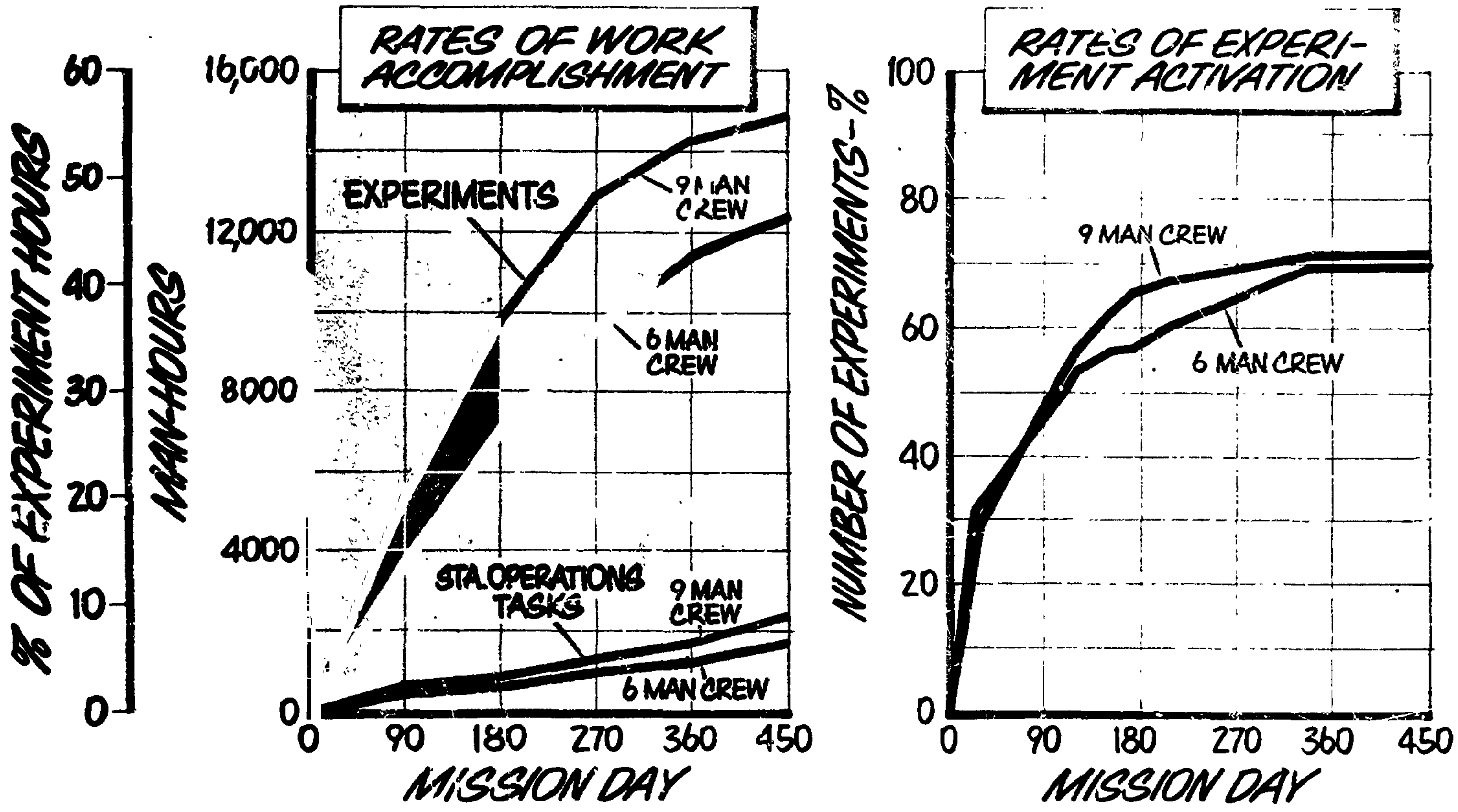


Figure 14-

The plot on the right side of Figure 14-9 indicates the relative frequency with which experiments are started. It may be noted that very few experiments are scheduled after mission day 360 for either the six-man or the nine-man crew. This is, of course, due to the reasons cited above.

14.3 Summary of Model Studies

The scope of problems covered by the Preliminary Requirements Model, Planning Mode, and Simulation Mode is shown in Figures 10, 11, and 12, respectively. The total spectrum of model studies is shown in Figure 13.

Two sample results (Fig. 10) obtained with the PRM illustrate the effects of astronaut cross-training and the effects of crew size. In the crew size study, three men were optimized for all but the two-man case. For this case, both crewmen were optimized.

Some typical results from the Planning Mode, shown in Figure 11, illustrate the types of data that can be obtained in the areas of logistics payloads, crew work profiles, and cost/effectiveness.

The scope of the Simulation Mode is shown in Figure 12 along with the time of occurrence for unscheduled events and the cumulative unscheduled crew time required for one of the checkout problems.

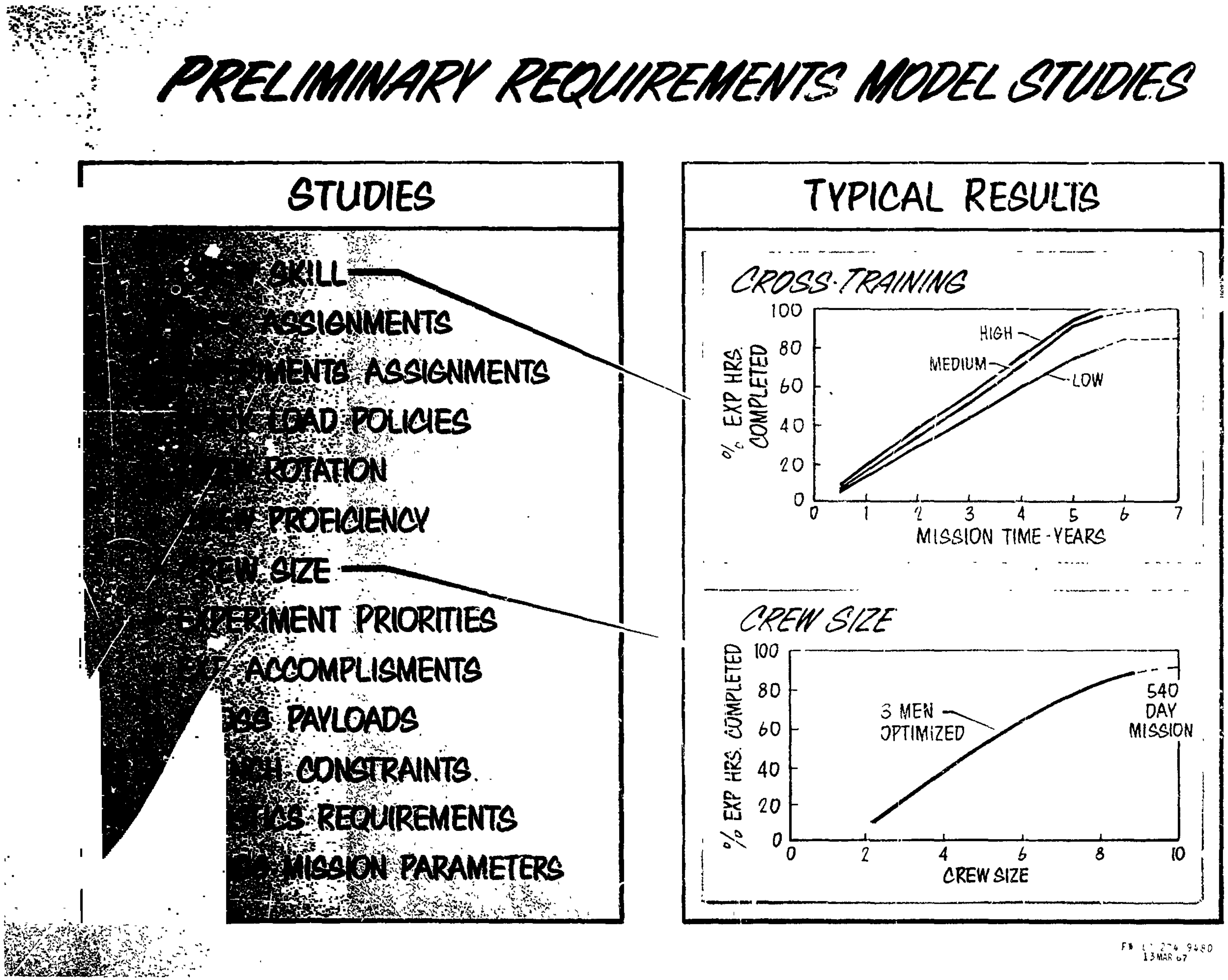

PRELIMINARY REQUIREMENTS MODEL STUDIES
STUDIES
SKILL
ASSIGNMENTS
ASSIGNMENTS
LOAD POLICIES
ROTATION
PROFICIENCY
SIZE
PRIORITIES
ACCOMPLISMENTS
PAYLOADS
CONSTRAINTS
REQUIREMENTS
MISSION PARAMETERS
TYPICAL RESULTS
CROSS-TRAINING
% EXP HRS. COMPLETED
HIGH
MEDIUM
LOW
MISSION TIME - YEARS
CREW SIZE
% EXP HRS. COMPLETED
3 MEN OPTIMIZED
540 DAY MISSION
CREW SIZE

Figure 14-10

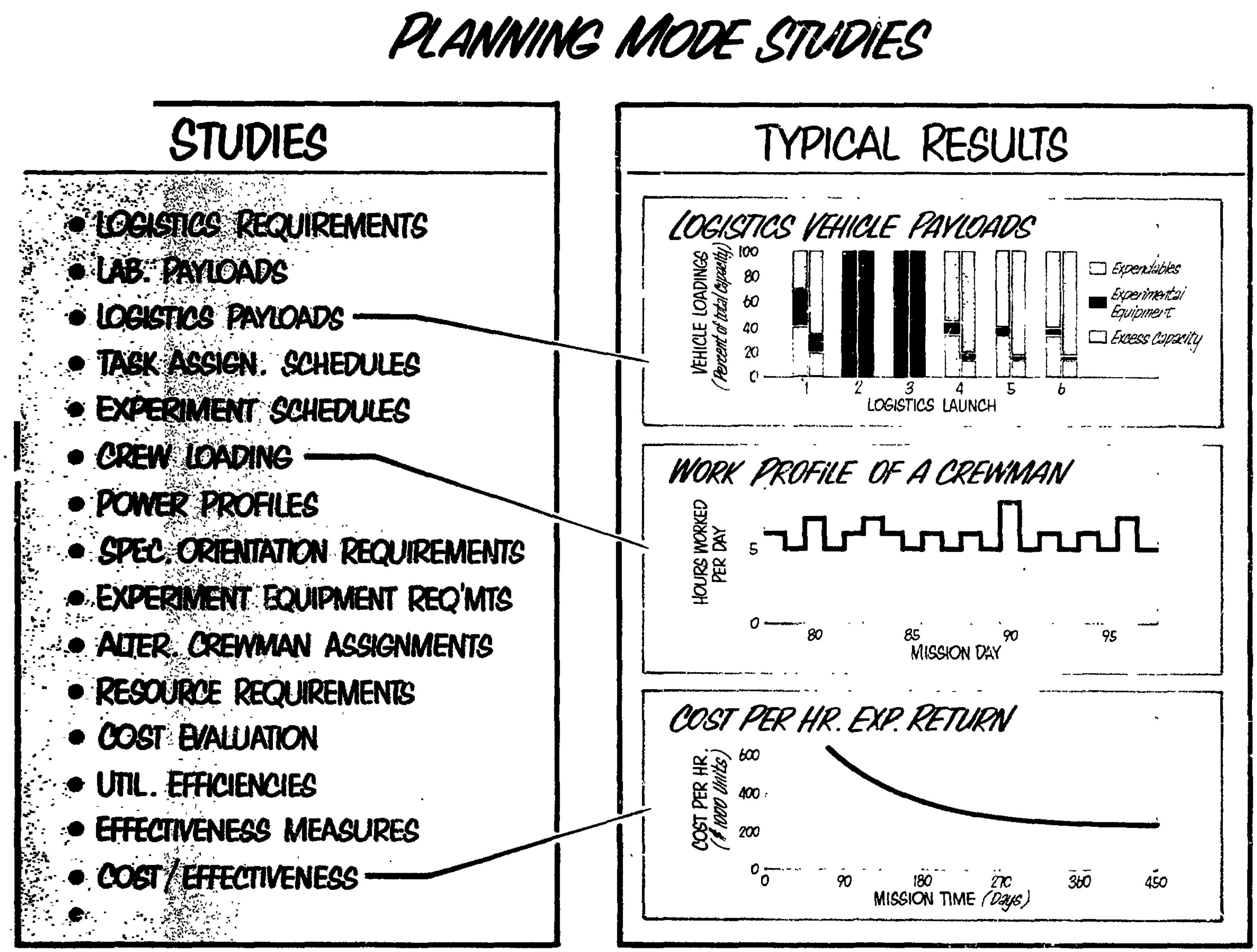

PLANNING MODE STUDIES
STUDIES
LOGISTICS REQUIREMENTS
LAB. PAYLOADS
LOGISTICS PAYLOADS
TASK ASSIGN. SCHEDULES
EXPERIMENT SCHEDULES
CREW LOADING
POWER PROFILES
SPEC. ORIENTATION REQUIREMENTS
EXPERIMENT EQUIPMENT REQ'MTS
ALTER. CREWMAN ASSIGNMENTS
RESOURCE REQUIREMENTS
COST EVALUATION
UTIL. EFFICIENCIES
EFFECTIVENESS MEASURES
COST/EFFECTIVENESS
TYPICAL RESULTS
LOGISTICS VEHICLE PAYLOADS
VEHICLE LOADINGS (Percent of total capacity)
100
80
60
40
20
0
1
2
3
4
5
6
LOGISTICS LAUNCH
Expendables
Experimental Equipment
Excess Capacity
WORK PROFILE OF A CREWMAN
HOURS WORKED PER DAY
5
0
80
85
90
95
MISSION DAY
COST PER HR. EXP. RETURN
COST PER HR. ($1000 Units)
600
400
200
0
0
90
180
270
360
450
MISSION TIME (Days)

Figure 14-11

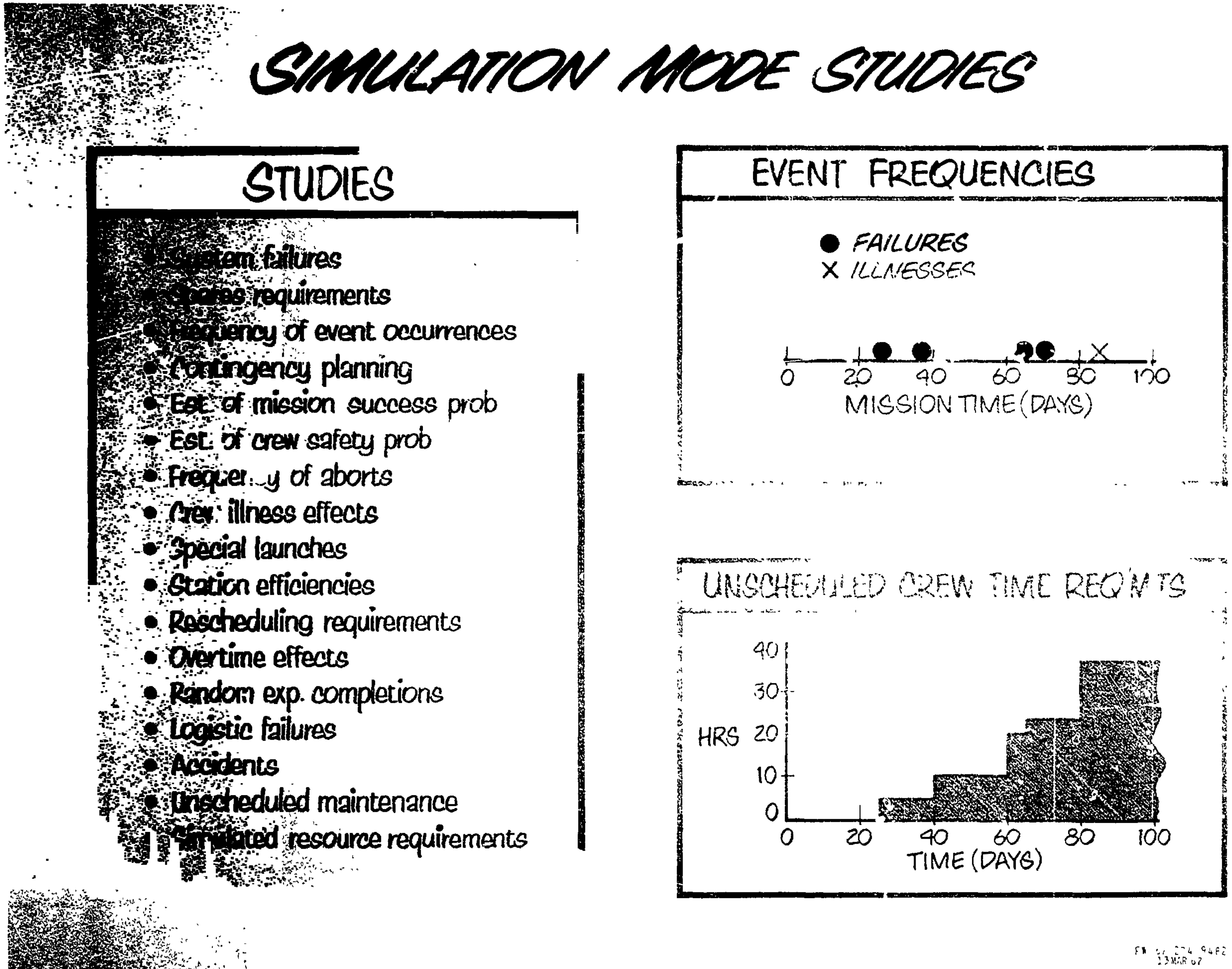
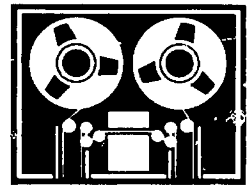

SIMULATION MODE STUDIES
STUDIES
• failures
• requirements
• of event occurrences
• planning
• Est. of mission success prob
• Est. of crew safety prob
• of aborts
• illness effects
• Special launches
• Station efficiencies
• Rescheduling requirements
• Overtime effects
• Random exp. completions
• Logistic failures
• Accidents
• Unscheduled maintenance
• resource requirements
EVENT FREQUENCIES
● FAILURES
X ILLNESSES
0 20 40 60 80 100
MISSION TIME (DAYS)
UNSCHEDULED CREW TIME REQ'MTS
HRS
40
30
20
10
0
0 20 40 60 80 100
TIME (DAYS)

Figure 14-12

SPECTRUM OF MODEL STUDIES



MISSION PARAMETERS	SCHEDULING ANALYSIS	CREW CONSIDERATIONS	LOGISTICS	SYSTEMS	EXPERIMENTS
• START DATE	• INITIAL SCHEDULES	• CREW REQ'M'TS	• LAB. LAUNCH RELIABILITIES	• RESOURCE REQ'M'TS	• TELEMETRY REQ'M'TS
• ALTITUDE	• RESOURCE PROFILES	• CREW SIZE	• LOGISTIC LAUNCH RELIABILITIES	• SPARES	• COMPLETIONS
• INCLINATION	• SPECIAL EVENTS	• SCHEDULES	• LAUNCH SCHEDULES	• FAILURE ANALYSES	• NO. SCHEDULES
• COST / EFFECT	• EVENT TERMINATIONS	• PROFICIENCIES	• VEHICLE UTILIZATION	• OPERATIONAL REQ'M'TS	• MAN-HR. REQ'D
• CONSTRAINED or UNCONSTRAINED	• SCHED. INTERFACES	• ASSIGNMENTS	• PAYLOAD COMPOSIT'NS	• MAINT. REQ'M'TS	• TYPES
• ALTERNATE CONC'PTS	• PRIORITIES	• SKILL REQ'M'TS	• TYPE OF VEHICLES	• RELIABILITIES	• PRIORITIES
• OBJECTIVES	• TIME IN SPECIAL ORIENTATION	• ROTATION PLANS	• SPECIAL LAUNCHES	• SPECIAL SUPPLY REQUIREMENTS	• PACKAGE SIZES
• SUCCESS PROBABILITIES	• EFFICIENCIES	• CREW SAFETY	• MODULE REQ'M'TS	• STA. EFFICIENCIES	• EQUIP. REQ'D
• MISSION PARAMETERS	• RESCHED. EFFECTS	• PERSONAL REQ'M'TS	• LAUNCH CONSTRAINTS	• INTERACTIONS	• VALUE
	• LOGISTICS ARRIVALS	• ILLNESS EFFECTS	• LIGHTING CONDITIONS	• OUTPUT LEVELS	• SPECIAL ATTITUDE REQUIREMENTS
		• EXTENDED WORK PER.		• POWER PROFILES	• RATE OF ACCOMP.
		• UNSCHED. TASKS			• EXP. STRUCTURES
		• DIST. OF TASKS			

Figure 14-13

GLOSSARY

Abort statements: FORTRAN statements which combine a series of variables to determine if abort conditions exist. The variables which are combined represent the status (failed or unfailed) of components comprising a laboratory subsystem. The statements combine the variables in a fashion which represents the combination of essential components within a subsystem. There is one statement for each subsystem.

Active period: The number of days within an experiment cycle during which resources are required (e.g., an experiment that requires resources two days out of every three has an active period of two days).

Alogrithm: A methodology for computation.

Alternate mode (of operation): Given one means (group of components, etc.) of performing a given function with a laboratory subsystem, an alternate mode of operation is an additional means (a different group of components, etc.) of performing the function.

Baseline: MORL Phase II study results.

Batch Scheduling: Scheduling of experiments in the PRM without regard to priorities. With this type of scheduling, it is sought to schedule the greatest amount of experimental work consistent with the constraints of available crew time.

Belly-down mode: The orientation of the space station with respect to the Earth; in particular, the longitudinal axis is in the direction of travel, i.e., parallel to the Earth's surface (see inertial mode).

Bernoullie trial: An event which assumes a fixed probability of occurrence for a single trial.

Block inputs: Model libraries.

Building block approach: Modular approach of developing and checking special-purpose routines separately and then integrating them into the overall mode.

Coefficient of variation: A measure of the relative variation of a random variable.

Confidence interval: The set of values between two determined values, t_1 and t_2, of a statistic t so that, for the parameter being estimated, the following probability statement is true percent of the time.

$$P(t_1 \leq 0 \leq t_2) = \gamma$$

Constrained/unconstrained mission: A PRM program option: a constrained mission is terminated on a specified day; an unconstrained mission is terminated when all experiments have been scheduled.

Constraints: Limits on resource levels such as man-hours, power, weight, volume, etc., which serve to limit the scheduled activity on board the space station.

Contagious illness: An illness which endangers the life of an astronaut unless returned to earth for treatment and which, due to its infectious nature, may endanger all astronauts on board the space station. (See major, minor illnesses).

Contingency: Events which happen at random times during the mission.

Continuous variable: A random variable is said to be continuous if it can assume any value within a given interval.

Cost arrays: A set of matrices containing cost data.

Cost/Effectiveness: Usually expressed as an efficiency index in which cost (or other penalty) is divided by effectiveness (accomplishment).

Crew proficiency: Degree to which a crewman possesses the ability to perform the required tasks.

Crew rotation plan: A model input specifying the particular period of time during which each crewman is to be in the space station.

Critical: With respect to classification of failures, a critical failure will cause mission failure unless repaired; however, the allowable downtime is great enough that special resupply of a spare is feasible (see supercritical; degradation).

Cross-correlation: A process of determining the significance of variations one upon the other among a set of parameters.

Degradation: With respect to classification of failures, a degradation failure will not result in mission failure if unrepaired. (See critical, supercritical).

Discrete variable: If a variable X can assume only a finite set of values X_1, $X_2, \ldots,$ X_K, with respective probabilities P_1, $P_2, \ldots,$ P_k of assuming a given value, the variable X is said to be discrete.

Dynamic experiment priorities: Priorities, which vary daily, of experiments and tasks to be scheduled - based upon number of opportunities remaining to be scheduled, value of the experiment or task, and total number of hours required.

Effectiveness: A measure of the capacity for performing a desired effect.

Event: An entry in the event table such as part failure, crew illness, etc. In the scheduling section, event refers to any task or experiment to be scheduled.

Event processing: The action required of the model at the time of occurrence of a random event, e.g., inventory adjustment, interruption of in-progress events, scheduling, etc.

Event-sequencing: In the event-sequencing method of simulation, the computer is programmed to proceed directly from one event to the next, ignoring those intervals of time in which there is no change in the system status.

Event termination: The special routine which handles the completions of random length experiments.

Experiment structure: The periodicity of the resource requirements of the experiments. Various experiments may require resources once every day, once every two days, etc.

Fixed events: The fixed events are those events whose time of occurrence can be expressed deterministically.

Fixed equipment: A category of cargo to be delivered to the laboratory.

Ford-Fulkerson theory (of flows in networks): An approach to that part of linear programming theory known as "transportation problems" or "network flow problems" as put forth in Flows in Networks (L. R. Ford, Jr., D. R. Fulkerson; Princeton University press, Princeton, N. J.; 1962).

Force start date: A Planning Mode descriptor specifying a particular mission day on which an experiment is to be started.

Heuristic rules: Rules of thumb for limiting the search for an optimum solution; however, unlike an alogrithm, there is no guarantee of obtaining the exact optimum solution.

Hohmann transfer: The minimum energy transfer between two circular coplanar Earth orbits.

Inertial mode: Refers to the orientation of the space station with respect to the Earth. In particular, the longitudinal axis is approximately perpendicular to the surface of the Earth. (See belly-down mode).

Integrated studies: A set of studies in which the interfaces are compatible by design.

Inverse probability integral transformation: A method for selecting random variates from any probability distribution function.

Launch site illumination angle: Used in determining the lighting conditions at the cape during the launch window.

Lighting condition constraints: Allows or disallows the consideration of night launches.

Logistics turnaround time: The time required to cycle a logistics vehicle through the delivery and preparation procedures at the launch complex.

Major illness: An illness which endangers the life of an astronaut unless he is returned to earth for treatment. (See contagious illness, minor illness).

Minor illness: An illness which does not endanger the life of an astronaut, but temporarily incapacitates him. (See contagious illness; major illness).

Mission: Mission is interpreted in this report as the time from station lift-off until the last crew returns.

Mission abort: An abandoning of the space station (if manned) and termination of the mission before its planned completion.

Model libraries: Blocks of data, usually of a specific type such as experiment or task descriptors, which are subject to infrequent change.

Model operational sequence: The sequential order in which the model routines are called.

Nonparametric confidence interval: It is not dependent upon the form of the distribution from which the sampling is being done.

Optimistic, pessimistic, and expected duration: Model inputs which are used by the Simulation Mode in making a probabilistic determination of the duration of an experiment. The optimistic duration is a low estimate of the experiment duration, the pessimistic duration is a high estimate, and the expected duration is an estimate of the actual value expected.

Optimized stay-time: Stay-time refers to the maximum amount of time which the crew may stay on board the space station without exhausting expendable supplies. Optimized stay-time is the stay-time resulting from an optimization procedure in the ordering of expendable supplies.

Parking orbit: The logistics vehicle is initially launched into an elliptical orbit of 100 n.m. perigee and apogee equal to the space station altitude.

Personal requirements: Requirements of the crew's time for personal activities such as sleeping, eating, etc.

Precision level: The width of a confidence or tolerance interval.

Predecessor/successor designations: Planning Mode descriptors which specify the sequence in which certain experiments are to be performed.

Principal/alternate crewman: A principal and an alternate crewman is designated for each experimental or station keeping task to be scheduled by the Planning Mode. During the scheduling of these tasks, the program will assign the task to the principal crewman if his available working hours permit. Otherwise, the program will attempt to assign the task to the alternate crewman.

Problem data: Those program input variables which are to be subject to frequent change and modification.

Program: Interpreted in this report as the development required prior to a mission as well as the mission itself.

Program interfaces: Regular fixed intervals of time in which no launch is to be made.

Random-keyed task (experiment): Any contingency task which must be performed at random time intervals or one of the experiments which has a random duration.

Recovery force: Air and water vehicles deployed during the manned launches.

Replacement level: The level (component, module, subsystem, etc.) at which failed equipment is replaced with spare equipment.

Resource allocations: The division of resources among various uses.

Screening studies: Processes to eliminate from further study those cases outside the field of interest.

Simulation descriptors: A class of experiment descriptors used in probabilistic mission simulations.

Skill cross-training: The degree to which one man possesses proficiency in several of the scientific skills required during the mission.

Skill-mix: A 1 x 20 array in which the proficiency of a crewman in each of 20 skills is specified by means of the code numbers, 1 (full proficiency), 2 (partial proficiency), and 0 (no proficiency).

Skill optimization: The assignment of scientific skills to crewmen in such a manner as to produce the best utilization of the time available for work.

Specialist: A person whose training has been directed toward the development of competence in a particular skill.

Special launch: An unscheduled or rescheduled logistics launch to satisfy emergency requirements.

Standard deviation: A measure of dispersion of the possible values the random variable can take on.

Standby philosophy: The philosophy used in readying emergency logistics vehicles at the launch complex.

Study milestones: Key events which transpired during the study and thus provide a measure of progress.

Suboptimization: An optimization which was not made in context with the total systems mission and which could result in an erroneous conclusion.

Supercritical: With respect to classification of failures, a supercritical failure will cause mission failure unless repaired; additionally, the allowable downtime is small enough that special resupply of a spare is not feasible. (See critical, degradation).

Task time factor: A measure of the proficiency of a man in a given skill. The task time factor of a man in a given skill is the ratio of the number of man-hours required by that man to perform a task requiring that particular skill to the number of man-hours required by a man with full proficiency in the skill.

Time-slicing: In the time-slicing method of simulation, the computer is programmed to observe the system status at regular fixed intervals of time.

Tolerance interval: An interval which covers a fixed portion of the population of values with a specified confidence.

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